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VERTICAL BURROWING AND SURVIVAL OF SPHAERIID CLAMS UNDER ADDED SUBSTRATES IN POOL 19, MISSISSIPPI RIVER

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ABSTRACT. An experimental study was conducted to determine whether sphaeriid clams can burrow upward through substrates placed upon them and survive. Sections of the river bottom containing large numbers of *Sphaerium transversum* and *S. striatinum* were isolated, and various depths of three types of substrate—sand, silt, and a sand-silt mixture—were placed upon them. Adult clams showed poor survival with added sand and somewhat better survival with the addition of silt or the sand-silt mixture. Survival of adult clams of both species was inversely related to both particle size and depth of added substrate. Juvenile clams had higher survival rates than adults.

INTRODUCTION

Each year, thousands of ducks use Pool 19 of the Mississippi River as a stopping place in their annual migrations. It has been estimated that 90% of the diving ducks using the Mississippi Flyway use the pool each fall (Brigham, 1971). Heavy use of the pool by the diving ducks is due partially to the large population of sphaeriid, or fingernail, clams available there as a food source (Wilds, 1973). Formerly the Illinois River valley was an important stopping place for diving ducks using the flyway. Prior to 1955 this area also supported large populations of sphaeriid clams. However, in 1955 and 1956, increases in water pollution seemingly caused a drastic decline in the number of fingernail clams, which coincided with a similar decline in the number of diving ducks using the Illinois River (Mills et al., 1966). Probably some of these ducks began to use Pool 19 as an alternate stopover.

In 1966 the Congress authorized the U.S. Army Corps of Engineers to begin planning for the construction of a barge harbor and access channel to a proposed industrial park below Fort Madison, Iowa, on the pool. At the time of this writing, dredging had not yet begun because of a lack of right-of-way and dredge dumping facilities. Original plans called for the dumping of hydraulic dredgings in the river (Gale, 1969). Current plans call for the construction of two, possibly three, dikes in adjacent sloughs and land areas, behind which the tailings will be placed (Corps of Engineers, 1975, personal communication). Thus settling basins will be formed, permitting solids to settle out of suspension, and allowing the remaining water to flow over the dikes to the river.

Effects of the massive dredgings necessary to the project on the ecology of the pool are largely unknown. Iowa State University sent graduate students to the pool from 1967 through 1970 to study the fish and wildlife of Pool 19 (Jude, 1968; Ranthum, 1969; Thompson, 1973; Wilds, 1973) and to gather data on the fingernail clam (Gale, 1969; 1971). The research that evolved from these studies not only shed some light on the basic ecology of Pool 19, but also made some of the first observations on the life history of the sphaeriid clam in the pool.

The purpose of this study was to determine if fingernail clams could burrow upward through added substrates of various depths and particle sizes.

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LIFE HISTORY AND ECOLOGY OF THE SPHAERIID CLAM

Sphaerium transversum is found in 28 states, 6 Canadian territories, Mexico, and has been introduced into England (Herrington, 1962). In Pool 19 it is by far the most abundant mollusk, with numbers of up to 100,000/m^2 being reported (Gale, 1969). It is found in most substrates in the pool and in all depths of permanent water. In a laboratory experiment Gale (1971) found *S. transversum* to prefer a mud substrate, but factors such as predation and competition may dictate the type of substrate in the field.

S. transversum is viviparous and hermaphroditic. Adults produce young in Pool 19 from early summer to late fall in Pool 19, which resemble the adults and range in length from 1.2 to 2.5 mm (Gale, 1969). Gale also found a correlation between length, and possibly age, of clams and their distribution in the substrates, with the smaller clams being deeper. He theorized that some young clams may be in a form of dormancy for part of their first year of life and at that time they do not need direct contact with the water column.

S. transversum is a nonselective filter feeder. Gale and Lowe (1971) found that it actively ingested phytoplankton at all seasons except late summer and midwinter.

Thompson (1973) found *S. transversum* and *S. striatinum* to be an important food source for the lesser scaup *(Aythya affinis)* and the ring-necked duck *(A. collaris)* in Pool 19. Fingernail clams constitute less food for the canvasback duck *(A. valisinaria)* and the golden-eye duck *(Bucephala clangula).*

The fingernail clam is an important fish food in the pool, with young channel catfish *(Ictalurus punctatus),* black bullhead *(I. melas),* carp *(Cyprinis carpio),* gizzard shad *(Dorosoma cepedianum)* using them as a main part of the diet at various times of the year (Jude, 1968). It should be noted that Pool 19 supports important commercial fisheries for at least two of these species (Helms, 1970).

STUDY SITE

Pool 19 with an area of over 150 sq. km is the second largest pool on the Mississippi River. It is about 68 km in length and varies in width from about 0.8 km to about 4 km, (Coker, 1929). The pool extends from Lock and Dam 18, 11 km above Burlington, Iowa, to Lock and Dam 19 at Keokuk, Iowa. Pool 19 may be conveniently divided into three regions. From Lock and Dam 18 to the Fort Madison bridge it is very river-like and has many wooded islands, fast chutes, and few backwaters. From Fort Madison to Montrose, Iowa, the pool is wide and lake-like. Gale (1969) found thermal stratification in this region in the summer of 1968. Here the pool is characterized by sloughs, backwaters, and shallow water immediately off the channel. From Montrose to Keokuk the pool is again river-like, but still resembles a lake in many areas.

Dam 19 was built in 1913 as a source of hydroelectric power; siltation has been a continuing problem. Gale (1969) indicated that the bottom level of the lower regions of the pool has risen 6 to 10 meters since the dam was built.

The site for this study was in the wide section of the pool below Fort Madison (Figure 1). Field work was conducted about 7.2 km downstream from the Fort Madison bridge in the extreme northeast corner of a large bay on the Iowa shore. There the current was slow and the site was often washed by waves generated by the wind and passing river traffic. The bottom was composed of a layer of clay-silt up to 10 cm deep covering a sand-silt or sand layer. There were occasional patches of exposed sand. The water depth ranged down to 1.5 meters.

Benthic fauna in the area included abundant sphaeriid and unionid clams and many gastropod mollusks. Mayfly larvae were noted in great numbers. Carlson (1968) found *Hexagenia* species naiads to be the dominant form of insect present in the benthos of the pool, and Gale (1969) did a detailed study of the pool's benthos. Shoreline regions that were protected from wave action showed many emergent plants, including water lilies *(Nymphaea, Nuphar,* and *Nelumbo* spp.) and arrowhead (*Sagittaria* spp.). Cattails (*Typha* spp.) were noted in most protected areas. The submerged pondweeds (*Potamogeton* spp.) and coontail (*Ceratophyllum* spp.) were seen in most areas of the bay, often in numbers large enough to foul the propeller of the boat motor. The bay and surrounding bottom lands supported a varied waterfowl fauna. Various species of ducks and herons were often seen. The proposed dredge-dumping sites for the barge harbor project are in the bottom land area surrounding the bay.

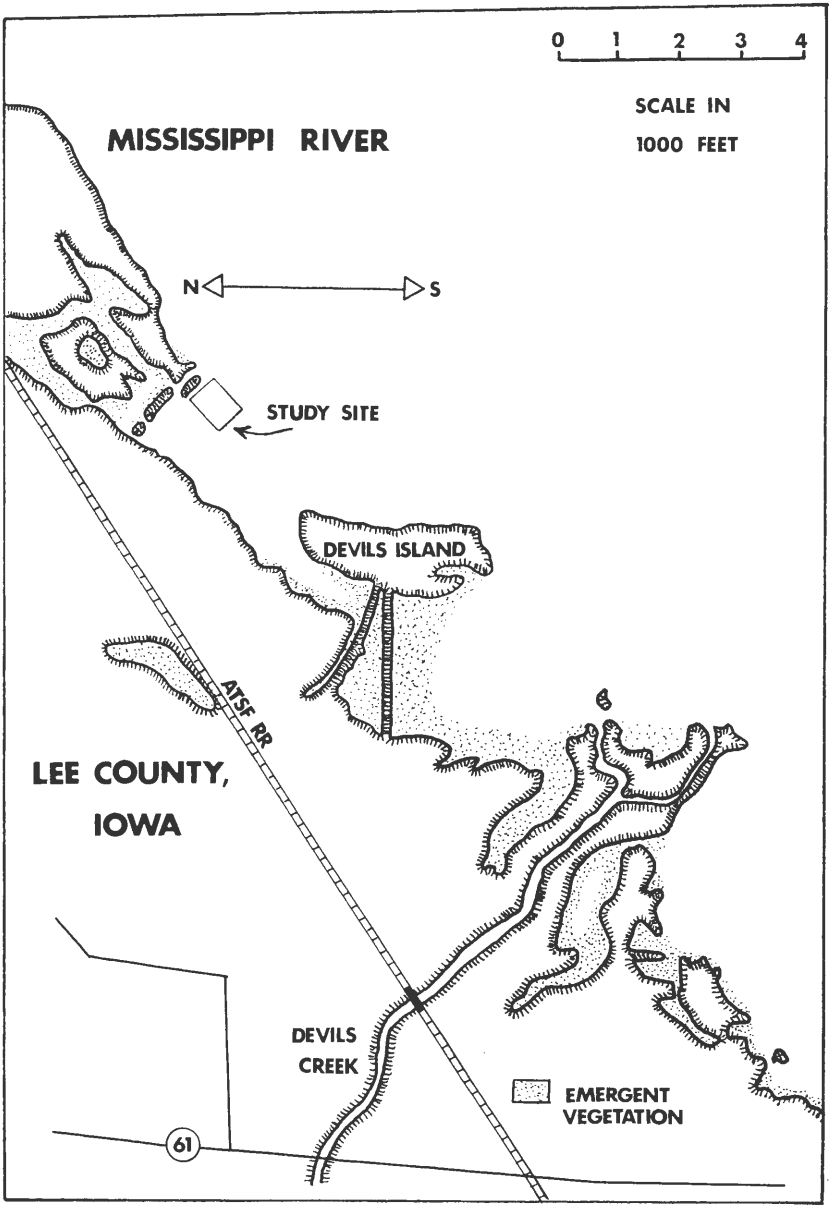

Figure 1. Map of the study area, beginning approximately 6.5 km downstream from the Fort Madison Toll Bridge.

Table 1. Counts of sphaeriid clams in core samples taken from control and experimental barrels during summer, 1972. Five core samples taken unless otherwise noted (*S. tr.* = adult *Sphaerium transversum*, *S. st.* = adult *Sphaerium striatinum*, Juv. = juveniles of both species). Counts were made 6 days after substrates were added.

Date unit sampled	Treatment	Mean depth of added substrate in mm	Median particle size, in Phi units, of added substrate or control	*S. tr.*[a]	*S. st.*[a]	Juv.[a]
	control[c]	0.0	3.0	11	0	7
June 30	sand[c]	86.5	0.5	2	1	1
	sand[c]	41.0	0.5	5	1	1
	control	0.0	3.3	17	1	16
July 7	sand	153.5	0.5	0	0	14
	sand	39.0	0.5	1	0	10
	control	0.0	5.8	46	2	28
July 16	sand	153.8	0.5	0	0	20
	sand	95.0	0.5	4	1	7
	control	0.0	3.5	43	3	27
August 15	sand	124.3	0.5	0	0	38
	sand	51.4	0.5	3	0	29
August 23[b]	control	0.0	4.5	30	5	46
	sand	106.5	0.5	0	0	43
	sand	27.1	0.5	2	3	40
June 24	control[c]	0.0	6.5	40	4	23
	sand-silt[c]	83.0	6.6	2	1	5
	sand-silt[c]	98.5	5.5	24	2	8
	control	0.0	5.3	41	0	18
July 15	sand-silt	92.7	5.3	11	3	12
	sand-silt	122.0	5.6	13	0	7
	control	0.0	4.4	36	6	21
July 23	sand-silt	157.9	3.4	0	1	31
	sand-silt[d]	83.0	4.5	11	2	20

August 3[b]	control	0.0	4.9	40	5	56
	sand-silt[d]	38.5	3.2	17	4	26
	sand-silt	61.9	2.8	21	5	31
June 28	control[c]	0.0	4.2	23	0	12
	silt[c]	65.6	6.5	14	0	12
	silt[c]	68.0	6.4	19	0	7
July 20	control	0.0	5.6	49	6	31
	silt[d]	117.0	7.8	2	0	12
	silt	94.6	9.6	17	1	18
July 27	control	0.0	5.3	18	5	27
	silt	49.6	8.1	8	3	17
	silt	73.9	8.5	12	2	27
August 1	control	0.0	4.0	30	1	25
	silt	68.6	7.2	23	0	10
	silt	155.2	7.4	4	0	13
August 4	control	0.0	4.4	73	7	37
	silt	49.6	8.1	9	0	9
	silt	73.9	8.5	21	2	43
August 24	control	0.0	4.0	27	4	47
	silt	85.5	5.8	16	5	36
	silt	30.6	4.9	17	7	35

[a]Sum of individuals in all cores.

[b]Counts made 7 days after substrates added.

[c]Three cores.

[d]Four cores.

The area was chosen as a study site because of the large numbers of fingernail clams present, the accessibility of the site by boat, and the partial protection from wave action afforded by the bay. In addition, the proposed access channel to the harbor cuts directly across the site.

MATERIALS AND METHODS

Field studies were conducted from June, 1972, to September, 1972. Nine 55-gallon steel barrels were scrubbed out, rinsed, and the ends removed. They were placed in the river over clam beds and sunk, end first, about 20 cm into the bottom. The barrels were placed in three units of three barrels each. Within each unit the barrels were placed in roughly triangular arrangement, usually less than 15 cm apart. The three units were placed near enough to each other to be convenient for wading between them. The tops of the barrels were usually underwater and wave washed.

Three different types of substrate—sand, silt, and a sand-silt mixture—were added to the units. The sand was obtained from above the water line on beaches on Devils Island. Silt was taken from a backwater known as Hoenigs Slough. This site was chosen as a source of silt because core sampling throughout the summer indicated few clams to be found there. No attempt was made to remove clams from the silt added to the units. Sand-silt mixtures were made by mixing the two types of substrate in a barrel.

Each unit received one type of substrate. One barrel in each unit was chosen as a control. Various depths of substrate were shoveled into the other two barrels. Substrates were transported to the units by boat. As two trips were usually made to each unit from the substrate source, the amount of sand in the sand-silt mixture might have varied even within one unit. Each unit was marked with a long pole that also served as a tie-up for the boat.

As the submerged barrels constituted a considerable boating hazard, the filled units were checked daily to insure that the marker poles were still standing. The units were not disturbed unless the level of the river had fallen enough to expose the tops of the barrels, in which case water in the barrels was bailed out and replaced with fresh river water daily.

The units were sampled by taking three to five cores from each barrel with a core sampler made by cutting PVC water tubing (I.D. 3.18 cm) into 76 lengths. If five cores were taken, one was taken from the center of the barrel and one from each quadrant. Each sampler was pushed through the added substrate to a depth of about 20 cm into the original river bottom, sealed with a #8 rubber stopper, and pulled from the barrel with an intact 20-40 cm core inside. The bottom of each sampler was corked to prevent the core from falling out in handling. The samplers were labeled and placed upright in an ice-water bath in the boat. It was felt that the bath would chill the cores enough to insure no movement of clams within the core. Clams are unlikely to move when disturbed, and they remain *in situ* while being frozen (Gale, 1969). A 200-400 gram sample of the added substrate in each experimental barrel and of the original bottom in the control barrel was collected for later particle size analysis. The next day the units were pulled from the river and again set up in an undisturbed spot.

The cores, wtill contained in the samplers, were quickly transported by boat to a laboratory that had been set up on the grounds of the Iowa State Penitentiary at Fort Madison. Each chilled core was carefully removed from the sampler into an enameled pan and cut into sections 13 mm long. Although occasional cores were destroyed in the process, those retained had minimal distortion. Usually the level of the original bottom was evident due to the differences in color and texture between it and the added substrate. Each 13-mm section was passed through a #18 ASTM sieve (1-mm-square mesh). This retained all clams in the section. The length (anterior-posterior) of each clam was measured by placing it along a plastic ruler taped to the stage of a dissecting microscope. Juvenile clams were considered to be those less than 2.5 mm in length and showing no gut contents or embryos. The clams were crushed to examine soft parts. No empty shells or shells containing partially decomposed soft parts were counted.

The particle size analysis was made using the Bouyocous hydrometer method (Dawson, 1959). The following modifications were made:

(1) The dry weight of each hydrometer sample was determined. Each field sample was thoroughly mixed with a small amount of water, and divided into two parts, both of which were weighed wet. One part was dried overnight in an oven (95° C) and reweighed. The percentage of dry solids in the original sample was determined.

The dry weight of the second part of the sample was determined by multiplying the wet weight by the fraction dry solids. This part was used as the hydrometer sample, which usually weighed between 100 and 200 grams.

(2) Hydrometer samples were permitted to deflocculate overnight in 125 ml of a solution containing 38 grams of Calgon glass cleaner in 1 liter of distilled water. The solution was remade weekly.

(3) Samples were not digested with an oxidizing agent.

(4) The deflocculated hydrometer samples were dispersed for 15 minutes in a commercial blender.

(5) Hydrometer readings were taken at 0.0, 0.5, 15, 30, 60, 480, and 1440 minutes. The temperatures of the suspensions were also taken at these times.

Particle sizes were expressed in Phi units (Krumbein, 1936) where

$$\text{Phi} = -\log_2(\text{particle size in millimeters}).$$

As the samples were not digested, these particle sizes were effective particle sizes, rather than the absolute sizes of the smallest particles present.

RESULTS

Fifteen units composed of 15 control barrels, 10 experimental barrels containing sand, 8 experimental barrels containing silt, and 12 experimental barrels containing mixtures of sand and silt were set up and sampled.

Table 1 contains the counts of surviving adult *S. transversum*, adult *S. striatinum*, and juveniles in core samples from each barrel. During June only three cores were taken from each barrel. Five cores were taken from each barrel during the remainder of the summer. Occasional cores were lost in handling. Core samples from controls yielded an average of 34.9 adult *S. transversum*, 3.3 adult *S. striatinum*, and 28.1 juveniles. In general more juveniles were found in the cores as the summer progressed. In most experimental barrels, shells containing decomposing adult clams were noticed at the level of the original surface. Though decomposing adult clams were not counted, their presence indicated mortality in the barrels. Few decomposing adult clams were found in the control barrels. No living adult clams were found at a depth greater than 39 mm below the surface of the added substrates, while few juveniles were found higher in the added substrates than 26 mm above the original surface.

Adult clams survived least in experimental barrels to which sand had been added. Adult *S. transversum* had 9% survival in the sand barrels, and adult *S. striatinum* had 14% survival in the sand barrels. Of adult *S. transversum* and adult *S. striatinum*, 31% and 51% respectively, survived being buried in the sand-silt mixture; 46% and 45%, respectively, survived being buried in the silt. There was little difference in the survival of juvenile clams buried in any of the three types of substrate, and the survival rates of juvenile clams were very high in all three types. Juvenile clams showed 70% survival in the sand, 63% survival in the sand-silt mixture, and 71% survival in the silt.

Correlation coefficients were computed between depth, in millimeters, of the added substrates and the logarithmic transformations of the total counts of clams in the core samples, and the particle size, in Phi units, of the added substrate and the logarithmic transformation of the total counts of clams in the core samples (Table 2). All logarithmic transformations in this paper were made by adding 1 to the total counts of clams in the core samples to avoid negative logarithms. Significant negative correlation was realized between depth and the logarithmic transformation of the count of adult *S. transversum* and depth and the logarithmic transformation of the count of adult *S. striatinum*. Significant positive correlation was realized between particle size and the logarithmic transformation of the count of adult *S. transversum*. It should be remembered that the Phi unit is a negative logarithm, so a large Phi unit indicates a small particle size. There was no significant correlation between particle size and the logarithmic transformation of the count of adult *S. striatinum*, particle size and the logarithmic transformation of the count of juveniles, or depth and the logarithmic transformation of the count of juveniles. It is possible that no significant correlation was realized between particle size and the logarithmic transformation of the count of adult *S. striatinum* because of the small sample size of adult *S. striatinum* (93 individuals). As over 1000 juvenile clams were examined, it is unlikely that small sample size is the source of insignificant correlation between depth, or particle size, and the logarithmic transformation of the counts of juveniles.

Table 2. Correlation coefficients between depth of added substrate, in millimeters, or median particle size of the added substrates, in Phi units, and the logarithmic transformations of the total counts of sphaeriid clams.

Variables	r
Depth and $\log_{10}$ (count of adult *S. transversum* + 1)	-.723**
Depth and $\log_{10}$ (count of adult *S. striatinum* + 1)	-.497**
Depth and $\log_{10}$ (count of juveniles + 1)	-.222[a]
Particle size and $\log_{10}$ (count of adult *S. transversum* + 1)	.482**
Particle size and $\log_{10}$ (count of adult *S. striatinum* + 1)	.096[a]
Particle size and $\log_{10}$ (count of juveniles + 1)	.068[a]

[a]Not significant at 0.05.
**Significant at 0.01.

The range of median particle sizes, in Phi units, in the control barrels was 3.0 to 6.5 (mean = 4.6). In the sand-silt barrels, the range of median particle sizes was 2.8 to 6.5 (mean = 4.6), and in the silt barrels the range of median particle sizes was 5.8 to 9.6 (mean = 7.5). All sand barrels showed a median particle size of less than 0.5.

Multiple regression techniques were applied to the data for adult *S. transversum*. The resulting expression is

$$\log (CSt + 1) = 1.045 + 0.007d + 0.099\phi$$

where log(CSt + 1) is the logarithmic transformation of the count of surviving adult *S. transversum*, d is the depth of the added substrate in millimeters, and ϕ is the median particle size of the added substrate in ϕ units. Depth and particle size accounted for 85.5% of the variation in the above model (Table 3).

Table 3. Analysis of variance for depth and particle size.

Source	df	Sequential SS	Partial SS	F
unit	14	3.51	1.38	1.53[a]
depth	1	6.37	5.95	92.75**
particle size	1	.70	.70	10.92*
error	28	1.80		
Total	44	12.38		

[a]Not significant
*Significant at 0.05.
**Significant at 0.01.

Figure 2 is a graph of the observed number of surviving *S.transversum* in each experimental barrel plotted against the expected number as predicted by the regression model.

DISCUSSION

Both adult *Sphaerium transversum* and adult *S. striatinum* displayed some abilities to burrow upward through substrates placed upon them and survive. Least ability to survive was seen in the experimental barrels to which sand had been added. Adult *S. transversum* had 9.1% survival and adult *S. striatinum*, 13.8% survival in the sand barrels. These barrels "capped", that is, the top centimeter of sand became so tightly packed from wave action that pushing a stick through it was often difficult. Little water could circulate through this cap, and possibly the low survival rates were due to anaerobic conditions in the sand barrels. Sand was the densest of the three types of substrate used, and it may be that the weight of the sand on the clams also inhibited burrowing. Gale (1969) found sphaeriid clams in all types of substrate in the pool except wave-swept sand and rock. Much of the bottom in the area of the proposed dredging is a shallow sand-silt layer covering a sand substrate.

Adults of both species survived much better in the sand-silt and silt barrels. The dredge tailings are to be placed behind dikes on land sites, the solids permitted to settle out, and the water permitted to return to the river over the dikes. It is conceivable that the water returning to the river will be carrying a heavy load of silt at times of high water or when dredging activity is at a peak. Some of this silt will be deposited on the clam beds in the river. The ability of sphaeriid clams to feed and reproduce in this silty water is unknown.

It is difficult to say exactly how deep a substrate load the clams can burrow through. No adult *S. transversum* survived more than 95 mm of added sand, or 122 mm of added sand-silt mixture. The maximum depth of any substrate that could be added to any barrel was 155-160 mm, as wave action washed substrate in excess of this out of the barrels. The maximum mean depth of silt found in an experimental barrel was 155.2 mm, and four adult *S. transversum* were found in five core samples from that barrel.

The regression model developed used the logarithmic transformation of the count of adult *S. transversum* surviving in the experimental barrels as the dependent variable, and depth and particle size of the added substrate as the independent variables. The high coefficient of determination (R^2 =85.5%) indicated that the two dependent variables were the major sources of variation. Unit effect was not significant (F=1.53), but both depth (F=92.75) and particle size (F=10.92) were significant.

Significant negative correlations indicated that as the depth of the added substrate increased, the number of surviving adult clams decreased. As the particle size of the added substrates increased, the number of surviving adult *S. transversum* decreased.

Juveniles, in contrast to the adult clams had high survival rates in all three types of added substrate but showed very little burrowing activity. In the sand barrels 70% of the juveniles survived, in the sand-silt barrels 63% survived, and in the silt barrels 71% survived. These data support Gale (1969) in his contention that juveniles need not be in contact with the water column to survive. He also found juvenile clams to be deeper in the substrate than the adults. How they get deeper in the substrate is uncertain. They may burrow down after being released from the parental brood pouches, or the adults may burrow down into the substrates and release their young there. The latter is an unlikely conclusion, as no adults were found deep in the substrates in any cores. When the juveniles are ready to begin feeding and reproducing, they may burrow upward, or depend on spring flooding to churn the substrates enough to deposit them at the surface.

Gale also described three groups of young clams within one growing season. Those born early in the spring rapidly reach maturity, reproduce, and then die off before the winter. Those born in the late spring, summer, and early fall reach mature stages by late fall and overwinter as adults. Those born in the late fall overwinter as juveniles and commence growth in the spring. This resumption of growth may lead to the formation of a calyculus. In the present study, young clams were found deep in the substrate throughout spring and summer. Juveniles made little attempt to burrow upward through added substrates in experimental barrels throughout the summer.

The proposed access channel will be about 100 meters wide, the harbor somewhat wider. Combined, both dredgings will cover approximately one-half the bay in which this study was done (Corps of Engineers, 1973, personal communication). The repeated dredgings in these areas will probably induce near total mortality of sphaeriid clams in the structures themselves. Too, the areas immediately to either side of the dredging will be subject to very heavy silt and sand loads from the dredging. High mortalities of sphaeriid clams will be likely in these areas.

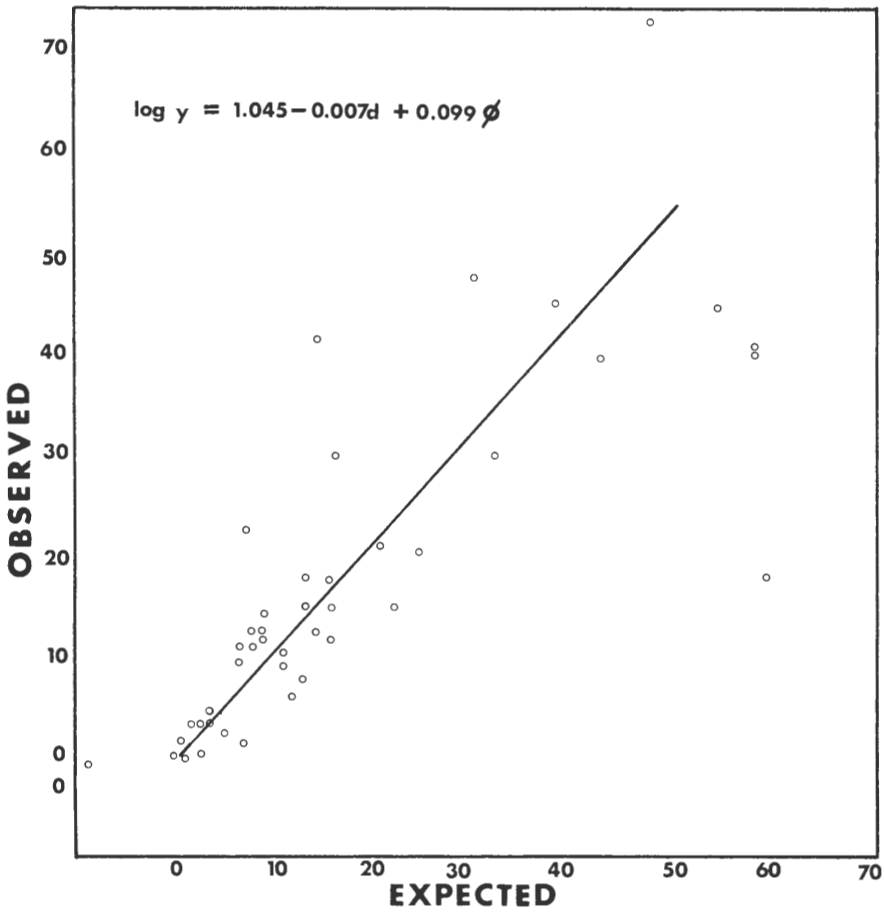

Figure 2. Number of adult *Sphaerium transversum* surviving in experimental barrels and number expected as predicted by the regression model.

The tailings, which will be removed from the river, will be placed behind dikes on nearby land sites. Water coming over these dikes may carry high silt loads during periods of high water or heavy dredging, and some of this silt will be dropped on the clam beds. Data indicate that adult *S. transversum* and adult *S. striatinum* could burrow upward through this silt fairly well, and less mortality should be seen in the area downstream from these dumping sites than in the areas immediately adjacent to the dredged channel.

Possibilities for recolonization of areas subject to substrate deposition are good. This study indicates that most juvenile clams survive being buried, although data are unavailable on the vertical burrowing abilities of young clams after they have been buried as juveniles. Clams from outside the dredged area may move laterally into the area. When *S. transversum* is kept in the laboratory, one can observe the clams raising their shells above the level of the bottom and moving slowly across the top of the substrate. Gale (1971) described *S. transversum* as actively seeking a preferred substrate by such lateral movements. Because sphaeriid clams are abundant throughout the whole pool, dredging at this one site is unlikely to cause much damage to the sphaeriid clam population in the entire pool, although drastic mortality in the areas being dredged may be seen.

This study dealt with the effects of the dredge tailings on the sphaeriid clam population in Pool 19. The construction of the barge harbor may cause problems other than siltation with regard to the ecology of the fingernail clam in the pool. Water pollution may increase with increased industrialization. The lessons learned on the Illinois River should not be ignored. Thornburg (1973) cites pleasure boating and sportsman movements as disruptive to diving ducks on Pool 19, and increased river traffic in the area of the harbor may disturb ducks feeding on the fingernail clams.

Pool 19 is a unique resource to the Midwest in that it supports such a large number of sphaeriid clams. Because the fingernail clam population is important in the ecology of the entire pool, man should direct his usage of the pool toward the path of least damage to it.

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HYDROCEPHALIC-POLYDACTYL, A RECESSIVE PLEIOTROPIC MUTANT IN THE MOUSE, AND ITS LOCATION IN CHROMOSOME 6[1]

W. F. Hollander[2]

ABSTRACT. The mutant here reported and symbolized *hpy* was discovered in 1964 among descendants of X-irradiated mice. Homozygotes show a variable syndrome typically including pre-axial polydactyly, a hopping gait, male sterility from defective tail formation in sperms, and often hydrocephaly. Mortality has been above normal in general. Mature specimens, especially females, often develop scoliosis, probably a connective-tissue weakness. Most females, however, can breed successfully for a time. The mutant is completely recessive and is located in linkage group XI between the markers *Sig* and *Hd* and close to *ob*. A significant sex difference in crossing over in this region of the chromosome is demonstrated, it being more than half again as much in female heterozygotes as in males. Combinations of this mutant with various others have shown mostly additive phenotypic effects.

INTRODUCTION

Mutant syndromes in the laboratory mouse have proved valuable as models for human developmental pathology as well as in the elucidation of normal processes. Complexity rather than simplicity seems the rule, and pleiotropic effects of single mutants have been remarkable. Reviews in this area include those by Grüneberg (1963), Kalter (1968), and Potter (1961). Exploration of the ramifications of such aberrations needs cooperative effort from various biological disciplines. The similarity of genetic mutant syndromes to terata induced by environmental agents suggests a need for broad training (Wilson and Warkany, 1965). The present report is an example of the range of discoveries and problems in the study of such a mutant.

ORIGIN AND PROCEDURE

Mice showing simultaneous hydrocephaly and pre-axial polydactyly were observed in 1964 among several litters in a stock derived from an X-ray experiment (Hollander, 1966 b). There had been considerable inbreeding for a number of generations since treatment, and the stock carried a previously reported mutant, extreme non-agouti (Hollander and Gowen, 1956).

Specimens with obvious hydrocephaly usually died before maturity or did not breed, and for a time the stock was increased from the normal relatives. Polydactyls with little or no definite hydrocephaly also were produced and survived fairly well. These were extensively tested, and the males proved consistently sterile. The females, however, generally were fertile and were able to raise their own young. Crosses with many other genetic stocks gradually provided a plentiful supply of abnormal specimens for study. The skeletal structures were prepared by alizarin-red sulphate staining. Microscopic examinations of semen and testicular material were made with various procedures and stains.

Further details on materials and methods will be provided in later sections, e.g., linkage tests.

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SYNDROME VARIATION

Variation seems typical of pathological syndromes, and this one shows a great deal. Not only has the hydrocephaly been of every degree, from extreme to seemingly none, but the polydactyly also varies more or less independently. Occasional mice were later classed as affected on other evidence.

It was noticed early that affected mice typically do not walk normally; instead, the hind legs tend to move in unison, with rabbit-like hopping (not leaping) action. Even in scratching, both hind feet commonly are used at once. Variation in such activity is considerable, and some individuals may seem nearly normal. The more obviously affected mice generally have deceloped scoliosis of increasing severity as they age.

Sterility of affected males has been complete so far as can be ascertained. However, the condition of the semen, sperms, and spermatogenesis has been quite varied; in some males it was near normal. Fertility in females also has varied extremely; poorest breeding seemed related to scoliosis.

Affected mice have a definite tendency to grow less rapidly than normal litter-mates and to have higher mortality in general. Therefore, early classification is essential for reliable statistical data, and the polydactyly is the best criterion at early ages.

The breeding program I have used would select any genetic tendency toward minimal expression of hydrocephalus; indeed, such a result seems to have been achieved.

RATIOS

In my first report (1966b) on ratios, a considerable deficiency of affected mice was noted; of 728 progeny from matings of two heterozygous parents, only 134 showed one or more features of the syndrome. Incomplete penetrance was proposed as the most likely explanation. Since that time many additional data have been accumulated, including also those on matings of homozygous females with heterozygous males. Table 1 presents the data in arbitrarily divided time periods, with the simplest classification (normal vs. abnormal in each sex). These data include a range of ages at which the classifications were first made, from newborn to weaning, so that losses from differential mortality would tend to distort the ratios. The actual ratios show just such a tendency, all but one being slightly below the expected 3 : 1 and 1 : 1, respectively. From these results, it seems no longer necessary to postulate incomplete penetrance of any significant degree. For inexperienced students, however, misclassification may be of some importance.

The data show a fairly consistent but slight excess of males, with no relation to the expression of the abnormality. The ratios therefore support the intuitive interpretation that a single mutant factor governs the hydrocephalic-polydactyl syndrome, and the symbol *hpy* proposed in 1966 will be used for this presumed mutant factor in the following discussions.

MORTALITY

Conditions in my laboratory are not rigidly controlled, so that overall mortality during the first month of life often has been as high as 25% of the total born. Infantile diarrhea periodically has plagued the colony. The mortality of *hpy* homozygotes, however, has seemed little related to such conditions, and an intrinsic weakness of some sort is probably the differential. No specific ailment has been noted, but these young seem less competitive than the normal young in the litter and tend to fall behind in growth. If they can survive to weaning age, their chances seem to improve markedly, and they may attain a normal life span.

HYDROCEPHALY

As noted, the frequency of hydrocephaly in the syndrome is inconsistent, and continual selection of females for breeding without evident hydrocephaly probably has favored minimal expression. It has been observed often that siblings are rather similar to one another in this condition, but both environment and heredity, of course, may be critical here.

The hydrocephaly typically is less evident at birth than at the age of two or more weeks (Fig. 1). Some individuals appeared quite normal at birth and developed obvious hydrocephaly later. In general, the cerebral region is most affected (Fig. 2). Even when the mouse has grown

Table 1. Segregation ratios in successive chronological periods. F_2 signifies mating between two heterozygotes. Backcross signifies mating between *hpy* homozygous female and heterozygous male .

Type of Mating	Period	Progeny				
		Normal		*hpy*		
		Male	Female	Male	Female	%*hpy*
F_2	A	402	379	102	112	21.6
	B	421	438	116	129	22.2
	C	312	268	99	86	24.2
	D	266	270	76	85	23.1
	E	294	320	105	78	22.9
	F	291	258	103	97	26.7
	G	240	222	81	70	24.6
	Total	2226	2155	682	657	23.45
Backcross	A	209	220	188	211	48.2
	B	202	182	172	164	47.3
	C	190	197	149	176	45.0
	D	145	110	111	98	45.0
	E	153	130	133	132	48.4
	F	184	192	209	148	48.7
	G	146	138	138	122	47.8
	Total	1229	1169	1100	1051	47.29

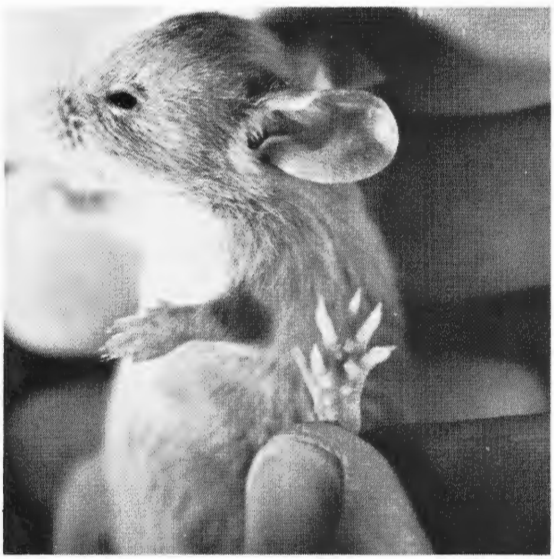

Figure 1. Hydrocephalic polydactyly: specimen about three weeks old. With obvious hydrocephaly like this, the animal is likely to die before maturity. The polydactyly here is fairly typical.

well, hydrocephaly has been a reliable sign that death will occur within a few weeks, and only one case is known in which such a female has produced offspring.

POLYDACTYLY

The most consistent feature of this syndrome has been pre-axial polydactyly involving the pollex as well as the hallux (Fig. 3). Some cases were similar to previously known polydactylous mutants; but all such mutants are quite variable in expression, and resemblance is of little aid in establishing identity. Sometimes, also, the polydactyly is merely incipient, a thickening of the hallux and pollex, and is easily misclassified as normal.

One can make a progressive series of the variation (Fig. 4) to show that, as the extra "hallux" becomes more separate from the first, it tends to diverge, develop more joints, and become more prominent (Fig. 5) and, finally, to become duplicated. The most extreme condition (Fig. 6) is rarely seen in unselected stock. Also, very rarely, a small post-axial extra digit occurs.

Asymmetry is fairly common for the right and left sides of the same mouse (Fig. 4). No marked tendency for greater expression to occur preferentially right or left has been observed. Very rarely a mouse has shown an extra hallux on one foot, but no abnormality of the other; if no additional features of the syndrome are evident, I interpret the condition to be a developmental "accident" and not homozygosity for *hpy*, although heterozygosity may slightly encourage it.

STERILITY

More than 100 of the polydactyl males have been mated with one or more normal females for extended periods, without any resulting pregnancies. To some extent this sterility was attributable to the males' lack of interest, although a few vaginal plugs were observed.

About 30 adult polydactyl males were killed for study of semen and spermatogenesis. Semen was stripped from the vas deferens and examined both in saline and in stained smears. Typically, the semen contained no normal sperms; sperms present, usually not abundant, were not motile and mostly were quite abnormal in having little or no tail and an elongated head (Hollander and Bryan, 1966). The semen also contained much granular debris.

Testes of the polydactyl males are essentially normal in structure, but study of spermiogenesis by Bryan (1968) revealed aberration in both head and tail formation. The normal heterozygotes had no such aberration or failure, and it was concluded that the haploid spermatid nucleus does not govern the processes in spermiogenesis.

Occasional polydactyl females also have failed to breed, for unknown reasons, but reproductive success generally is near normal. In many instances large litters have been produced, and maternal care has been quite adequate.

BEHAVIOR AND SCOLIOSIS

Even without evident hydrocephalus, abnormality of the nervous system is indicated by the hopping gait and the tendency to use both hind feet simultaneously in scratching the skin. The more obviously affected specimens tend to develop scoliosis after maturity, especially the females (Fig. 7). When scoliosis becomes severe, the animal is useless for breeding, and it seems incurable. No evident skeletal abnormality has been found, and presumably the condition is a connective-tissue dysfunction.

GENETIC LINKAGE TESTS

Search for linkage with the *hpy* factor has been protracted, and time was wasted on several false leads. The general procedure was to cross with a suitable marker type, then to record recombination data in F_2 and test-crosses. If no linkage appeared in a fair-sized sample, as in tests with albinism *(c)*, non-agouti *(a)*, naked *(N)*, pintail *(Pt)*, varitint *(Va)*, steel *(Sl)*, brachyury *(T)*, loop *(Lp)*, and others, the test was dropped, and another tried. If linkage seemed suggested from a test, it was extended, for rechecking and refinement. Such an extended test indicated linkage with waved-2 until I realized that the waved-2 tester stock had

Figure 2. Same specimen as in Figure 1, head and forefoot stained with alizarin-red sulphate and cleared in glycerine.

Figure 3. Left feet of a 2-week-old specimen, stained with alizarin and cleared in glycerine, showing common type of polydactyly. The pollex seems to be perfectly duplicated but the extra toe of the hind foot resembles one of the middle toes more than a hallux.

Figure 4. Pairs of hind feet showing various degrees of polydactyly and asymmetry.

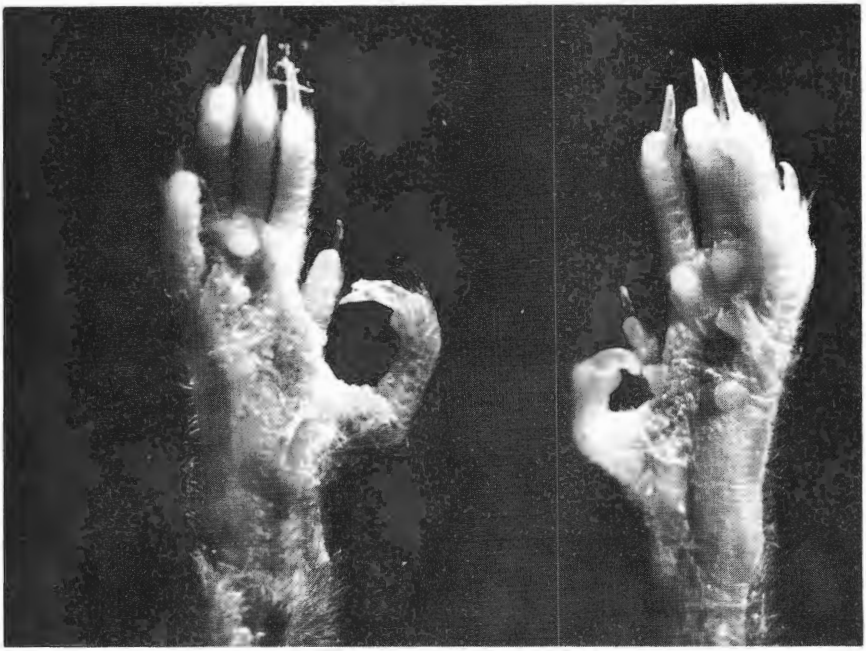

Figure 5. A pair of hind feet with extremely divergent extra toe.

Figure 6. Extreme polydactyl female, 3 weeks old. The hind feet approach complete doubling.

Figure 7. Three mature (age about 8 months) females showing scoliosis. The twisted shapes are maintained though not rigid.

been partly confused with waved-1 and that the tests were inconclusive. Further tests with waved-1 and other markers in linkage group XI finally resolved the difficulty and located the position of *hpy* in that group. New markers obtained from the Jackson Laboratory, Bar Harbor, Maine, were useful in this study, particularly *Sig* and *Hd*.

All the linkage tests have been test-crosses or their equivalent (Table 2). Where both parents were heterozygous for *hpy*, only the homozygous *hpy* progeny were utilized in linkage calculations. Several alleles at the *Mi* locus were available for use, but only Mi^{wh} actually was employed. Here again, if both parents were heterozygous for Mi^{wh}, only homozygous progeny were included in linkage calculations.

Table 2. Genetic linkage-test data obtained for four loci in Chromosome 6. All data are from test-crosses or equivalent. Where both parents were heterozygous for *hpy* or Mi^{wh}, only homozygous progeny were utilized in the calculations. S.E. is standard error.

	From male heterozygotes			From female heterozygotes		
Region	Total progeny	Cross-overs	S.E.	Total progeny	Cross-overs	S.E.
Sig - *hpy*	344	13.7%	1.8%	123	22.0%	3.7%
Sig - *Hd*	750	20.4%	1.5%	1171	32.4%	1.4%
hpy - *Hd*	304	9.8%	1.8%	103	8.7%	2.8%
hpy - *Mi*	1089	23.4%	1.3%	249	20.0%	2.5%
Hd - *Mi*	503	15.1%	1.6%	694	18.7%	1.5%

In the 10 years since publication of the second edition of the Biology of the Laboratory Mouse (Green, 1966), remarkable advances have been made in mapping the chromosomes and correlating the cytologic with the genetic data. Notable reports include the tests of *Hd* with *ob* (obese) by Hummel (1970), and of *Ldr-1* with *Mi* by Hutton and Roderick (1970), and by Itakura et al. (1972). Linkage group XI has been identified with chromosome 6 (sixth longest), and its centromere end is near the locus of the mutant *Sig* (sightless). A summary map prepared by Green (1974) shows the following sequence of loci, crossover values being set below for the map:

Sig		*ob*		*Hd*	*Lc*	*wa-1*	*Mi*	*Cd*	*me*	*Ldr-1*
•	14		13	4	8	5	10	9	11	

The total length, according to linkage-test data, therefore is more than 70 centimorgans. The locus symbols represent these names of mutants: *ob*, obese; *Hd*, hypodactyly; *Lc*, lurcher; *wa-1*, waved fur-1; *Mi*, microphthalmia (with multiple alleles); *Cd*, crooked tail; *me*, motheaten fur; and *Ldr-1*, lactate dehydrogenase regulator-1. Green (1974) used data from Hollander (1973a,b) on linkage of *hpy* with *mi* and *Sig* to place *hpy* about midway between *ob* and *Hd* in the map.

In 1974 Searle and Beechey reported a striking sex difference in the crossover frequencies for the *Sig* - *Lc* portion of this linkage group, the value from female heterozygotes being about double that of males. My own more extensive data, especially for the *Sig* - *Hd* region, confirm the existence of a sex difference, although it is less than twice as great a crossover frequency in female heterozygotes. As shown in Table 2 the male heterozygotes gave about two-thirds as much recombination as did females for the *Sig* - *hpy* and *Sig* - *Hd* tests. The tests of *hpy* - *Mi*, on the other hand, indicate no significant sex difference or recombination in that region of the chromosome.

The data in the *hpy* - *Hd* test are less reliable than the others, not only because of small numbers, but also because of more difficulty and error in classification. The results, however, agree in placing *hpy* between *Hd* and *ob*.

CHASE'S POLYDACTYLY

In 1951 Chase reported on a type of polydactyly in mice selected from mixed stock. Although a high incidence was obtained, only a low percentage of the mice were affected on both sides, the right being much more common. Inheritance was not simple, and a few polydactyls appeared in F_1 from crosses. Chase's stock still is available, and Mrs. Claudette A. Weissinger of Chase's laboratory kindly provided breeders, so that I could compare with *hpy*. The Chase mice showed no behavior or fertility problems, but the polydactyly of the hind feet resembled that of *hpy*.

From the two matings of Chase males with homozygous *hpy* females, 69 F_1 were produced, all normal except one with doubled right hallux. Matings of F_1 inter se gave more than 300 progeny, of which 63 showed polydactyly, quite varied in expression. Some examples seemed to be the Chase type, others the *hpy* type, and a number of the latter were of the more extreme sort, having triple halluces with hydrocephaly. These breeding results indicate that the Chase factor(s) may exaggerate the expression of *hpy*, but there seems to be no allelism involved.

OTHER COMBINATION EFFECTS

As might be expected, combinations of homozygous *hpy* with mutants affecting pigmentation or hair structure were found simply additive—each is expressed as usual. One partial exception is the combination with a pleiotropic allele of the *p* (pink-eyed-dilute) series, p^s, which affects not only pigmentation but also sperm development, tooth structure, and nervous behavior. Most of the numerous double homozygotes produced lived only a day or two after birth. This increased mortality effect might be considered either additive or multiplicative inasmuch as both mutants are somewhat inferior to normal in viability.

Certain other combinations have given effects meriting special attention. The double homozygote of *hpy* and *se* (short ear, chromosome 9) typically has had exaggerated scoliosis, perhaps because of the effects of *se* on connective tissues. The semidominant mutant *Hd*—hypodactyly (closely linked with *hpy*)—tends to reduce or eliminate the hallux; combined with homozygous *hpy*, it partly inhibits the polydactyly, but the "extra" hallux generally is less inhibited than the hallux next to the other toes. Some of these combination mice have had a nearly normal-looking foot structure, an interesting example of two mutants tending to cancel each other's actions. In the other direction increased polydactyly has resulted from combining the semidominant mutant *Ps*, polysyndactyly (chromosome 4), with homozygous *hpy*. And the mutant *Sig*, sightless (linked with *hpy*), which typically is characterized not only by eye defects but also by slight hydrocephaly, when combined with homozygous *hpy* has given exaggerated early hydrocephaly. All these combination effects, and others not described, seem fairly predictable and may give some insight into developmental mechanisms.

DISCUSSION

We seem to have here a single recessive mutant rather than a gross chromosome aberration; it has a well-defined locus in chromosome 6 and shows the same involvement in crossover phenomena of that portion of the chromosome as do other mutants. The sex difference of crossing over here is as surprising and inexplicable as is its occurence in other chromosomes, although there may be a rational connection with the heterochromatic structure (Dunn and Bennett, 1967).

This single mutant has profound effects on development and function. The pleiotropism is so extensive that a common denominator in cell constituents is not evident. The great variability likely depends, in part, on increased sensitivity to environmental influences. For example, hydrocephaly has been induced in normal mice by massive infection with viruses early in life (Holtz et al., 1966; Phillips et al., 1970). Analogous variability of genetic syndromes involving other mutants in the mouse as well as in other species has been well documented (Dooley, 1968; Grüneberg, 1963; Kalter, 1968). The hydrocephalic-polydactyl mutant will likely be of considerable further interest in embryological investigation, as with the "luxoid" mutants and others. Forsthoefel and Williams (1975) have extensively studied base-analogues' effects by means of such a sensitive mutant.

Genetically based hydrocephaly has been reported several times previously in mice, and a review has been given by Dorit and Sidman (1972). One such mutant also showed polydactyly (Green, 1965). This type, as well as most of the others, no longer survives in laboratory stocks. Johnson and Hunt (1971), in England, described a mutant that they named "hop-sterile," very similar to the present mutant, except that no hydrocephaly was observed. Their mutant arose in untreated mice in 1967 and presumably has no connection with the origin of *hpy*, although they may well be allelic. Also, another similar mutant (without hydrocephaly) was discovered at the Jackson Laboratory by Dr. C. P. Dagg in an untreated stock of C57/B1 6 mice. Dr. Don Varnum (personal communication, 1975) informs me that this mutant unfortunately was lost.

The almost incredible complexity of genetic mechanisms and variations encountered in this study is almost exactly the sort of picture that has been unfolding in studies with *Drosophila* and micro-organisms, not to mention other scientific fields. More and more elaborate procedures become necessary to study the new problems uncovered, and with the mice considerable effort is required to prevent extinction of the novel genetic mutants and combinations so that they may be available for future use. This effort seems well worthwhile in view of the unsolved mysteries in genetic control of development in higher organisms, and the *hpy* mutant seems of unusual pertinence.

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A RAPID METHOD FOR MEASURING NET PHOTOSYNTHESIS OF EXCISED LEAVES BY USING AIR-SEALED CHAMBERS[1]

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ABSTRACT. A system for rapid, convenient and relatively simple measurement of CO_2-exchange rates (CER) by infrared gas analysis is described. The system uses excised leaf sections that are placed into rectangular, air-sealed chambers. Leaf sections are initially preconditioned in separate preconditioning chambers before being placed in the measuring chamber. The leaf sections are placed between two plastic frames that aid in rapid insertion into and removal from the chambers. With our system CER rates of maize (*Zea mays* L.), reed canarygrass (*Phalaris arundinacea* L.), and soybeans (*Glycine max* [L.] Merr.) were of magnitudes similar to CER rates reported in the literature for these species. CER rates for both attached and excised maize leaves were comparable. With the system described 12-30 measurements can be made per hour. Excising leaves permits sampling at any location, and under most weather conditions. The system seems especially suited for plant-breeding programs that require evaluation of large numbers of genotypes at many locations.

INTRODUCTION

Net photosynthesis can be estimated by measuring CO_2-exchange rate (CER) of a leaf, plant, or plant canopy enclosed in a chamber. Such measurements have been used widely for physiological investigations, but have had limited use as a selection parameter in plant breeding programs. Although most techniques for measuring CER rates have been reliable, they have been slow and (or) inconvenient to use.

Several techniques for rapid measurement of attached leaves under field conditions by use of the infrared gas analyzer (IRGA) have been developed (Gloser, 1970; Nelson et al., 1974; Hansen, 1970). However, transporting the IRGA is cumbersome for it requires a warm-up period and a stable electrical source. Use of $^{14}CO_2$ for measurement of CER of attached leaves in the field (Austin and Longden, 1967; Shimshi, 1969) allows rapid measurement, but requires additional manipulation in the laboratory.

Other techniques have measured excised leaves by use of the manometric method (Wilson et al., 1969), the IRGA (Pearce et al., 1969; Goldsworthy, 1971), $^{14}CO_2$ uptake (Lawes and Treharne, 1971), and dry-weight increase (Johnston and York, 1971). Some of these have the disadvantage that part of the leaf is in contact with buffer or water. They do, however, eliminate the problem of moving equipment to the field. Gaastra (1959) suggested, but did not present evidence, that leaves of some species may be more sensitive to excision than others. Pearce et al. (1969) using *Medicago sativa* L., and Wilson et al. (1969) using *Lolium perenne* presented evidence that excising leaves did not affect relative CER of these species.

Wolf et al. (1969) and, later, Nelson et al. (1974) used air-sealed chambers that eliminate the need for clamping leaves within or between chamber gaskets. The chamber permitted rapid insertion and removal of leaves and offered increased reproducibility.

This paper describes a system that used excised leaf sections in air-sealed chambers. The system allows simplified, rapid, and accurate measurement of CER.

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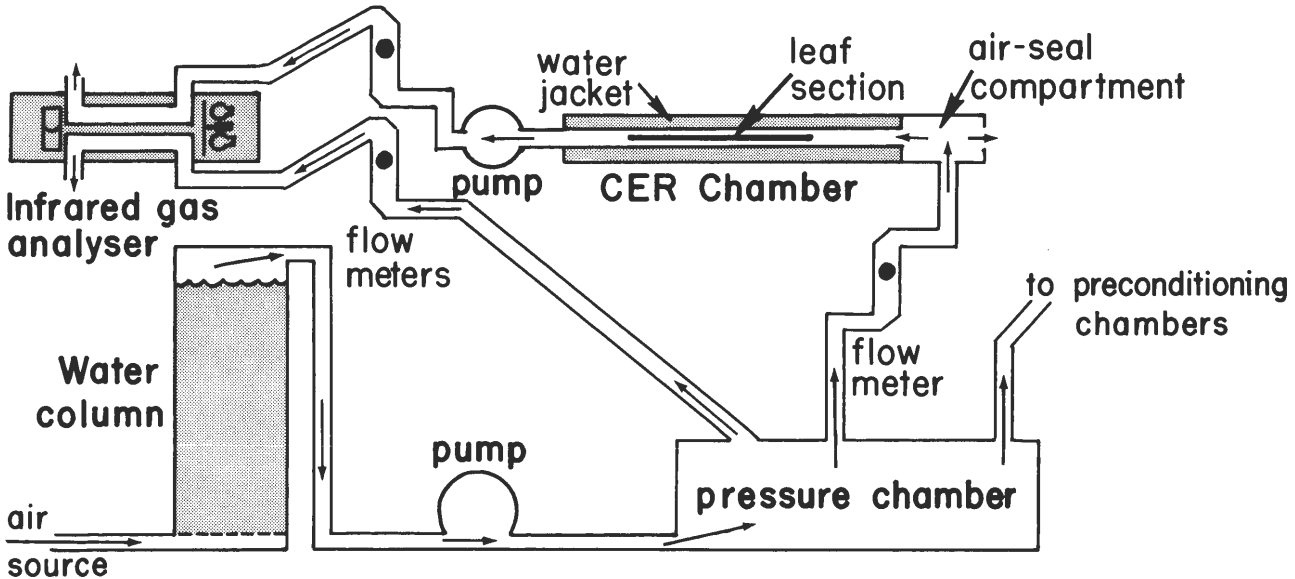

Figure 1. Basic system for measuring CO_2-exchange rate (CER) of leaf sections. The plastic frames supporting the leaf section have been omitted for clarity of illustration.

DESCRIPTION AND OPERATION

Our method for measuring CER uses leaf sections. The leaves are excised on location, brought into the laboratory, and sectioned; the sections are preconditioned in chambers used only for preconditioning. After preconditioning, sections are transferred to the chamber used for CER measurement.

The Basic System

Our basic system is illustrated in Figure 1. Air is drawn through a water column (to saturate it with water vapor and prevent desiccation of leaf sections) by a large diaphragm pump. Subsequently, air is pumped into a pressure chamber for distribution. The pressure chamber can supply several chambers if the pump has sufficient capacity. To measure CER, air is pushed into the air-sealed compartment of the CER chamber at a rate faster than the rate at which it is being pulled over the leaf section. This creates positive pressure and prevents laboratory air from entering the air-sealed compartment (Wolf et al., 1969). Air from the pressure chamber goes into the reference side of the infrared gas analyzer at the same time that air from the CER chamber is pumped into the sample side. The difference in CO_2 concentration between the two air streams is measured, and CER is calculated by the method of Hesketh and Moss (1963).

Both the sample and reference air streams are near (100%) saturation; therefore, air is not dried before measurement. To insure accuracy gases used in calibration also should be saturated with water by passing them through water columns.

CER Chamber

The chamber used for measuring CER is sealed by an air-seal compartment similar to that of Wolf et al., (1969). The chamber (constructed of plexiglass and surrounded by a water jacket to aid control of chamber temperature) is a rectangular tube (0.4 x 4.0 x 25 cm) into which two plastic frames are inserted (Figure 2). The plastic frames have a grid of nylon strings that support the leaf section(s), and one frame of each pair has a strip of foam rubber along each side. This keeps the two frames separated and reduces the effective cross-sectional area of the chamber to 0.4 x 2.0 cm. The plastic frames can be quickly inserted into or withdrawn from the chamber without laboratory air leaking into the air-sealed compartment.

Preconditioning

For most species 20 to 30 minutes exposure to light is required before CER of leaves reach equilibrium. Consequently, to make rapid measurements the leaves need to be preconditioned before CER is measured. Therefore, we have constructed one large chamber that contains six rectangular tubes and is identical to the CER chamber (Figure 3). The preconditioning chambers have a common water jacket and are illuminated by six low-temperature, incandescent bulbs. After a leaf section is cut, it is put into a pair of plastic frames and inserted into one of the preconditioning chambers (Figure 3). After 20 to 30 minutes the leaf section (in the plastic frames) is removed from the preconditioning chamber and inserted into the CER measurement chamber. Depending upon differences in conditions between the preconditioning chamber and the CER chamber, CER equilibrium can be measured in from 1 to 7 minutes.

Photosynthetically Active Radiation (PAR) and Temperature

For preconditioning we found that leaf sections are not overheated or desiccated when provided PAR (400-700 nm) of 700 to 900 uE $m^{-2} sec^{-1}$ (about 35 - 45 klx for low-temperature bulbs). If one is to measure CER at PAR saturation, however, a higher PAR may be required for the CER chamber. For example, maize (*Zea mays* L.) requires a PAR of 2300 uE $m^{-2} sec^{-1}$ (about 115 klx) to be near saturation, but reed canarygrass (*Phalaris arundinacea* L.) is light saturated at 900 uE $m^{-2} sec^{-1}$. Because of the difference in PAR for preconditioning and for CER measurement, maize requires more time in the measurement chamber (3-5 minutes) than does reed canarygrass (1-3 minutes), which requires preconditioning and measuring PAR of similar magnitudes.

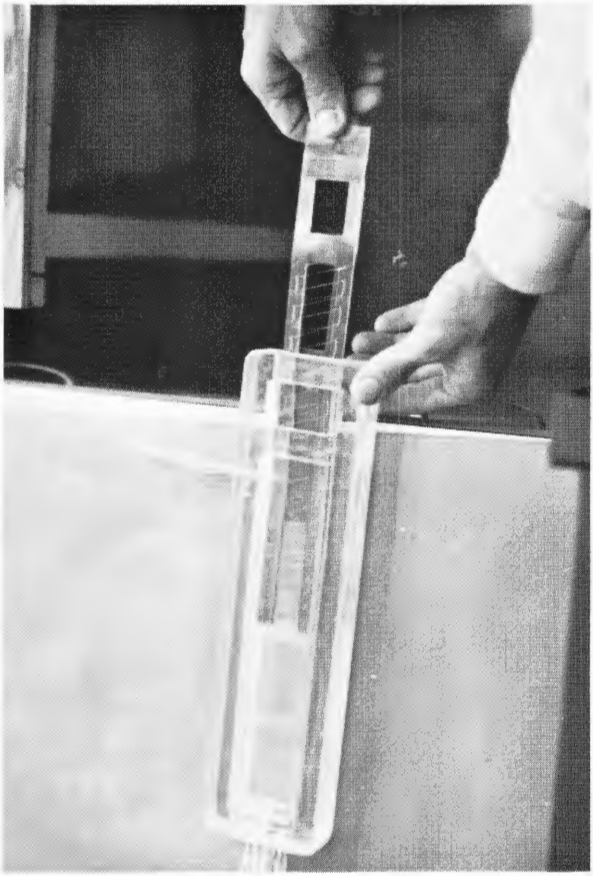

Figure 2. CO_2-exchange rate (CER) chamber with the plastic frames being inserted. The leaf section is located on the nylon grid between the edges of the frames.

Air and leaf temperature in the CER chamber can be modified by changing (1) water temperature in the water jacket, (2) flow rate of water through the water jacket, (3) temperature of air entering the chamber, (4) flow rate of air, and (5) amount of radiation. Leaf temperature is the best measure of the temperature influencing CER, but air temperature leaving the chamber is easiest to measure. Therefore, one should know the relationship between leaf and air temperature, a difference primarily influenced by type and amount of radiation. At the highest PAR that we use (2300 uE $m^{-2} sec^{-1}$), the difference between leaf and air temperature is 3°C.

Flow Rates

Two air flow rates need to be considered, the one being pumped into the air-sealed compartment and the one being drawn through the leaf-section compartment. In our studies a flow rate into the air-sealed compartment, 1.5 times greater than the flow rate of air being drawn through the leaf-section compartment, prevented entrance of laboratory air. This agrees with Wolf et al. (1969).

We studied effects of flow rates in the leaf-section compartment on CER of maize leaf sections. During the early vegetative stage of a field-grown, 3-way hybrid, we collected excised leaves from the last fully expanded leaf. Leaves were sectioned, sections were measured at one flow rate only, and flow rates were randomized within each of four replications. Results are presented in Table 1.

Table 1. Effect of flow rate on excised leaf CO_2 exchange rate (CER).

Flow Rate $l\ min^{-1}$	Calculated Air Speed ($cm\ s^{-1}$)	CER ($mg\ CO_2\ dm^{-2}\ hr^{-1}$)
1.0	20.8	51.5 a*
1.5	31.6	51.8 a
2.0	41.7	46.5 a
2.5	52.3	49.5 a
3.0	62.5	31.6 b
3.5	72.9	22.3 b
4.0	83.3	18.5 b

*Values with the same letter are not significantly different at the 5% level, using Duncan's Multiple Range Test.

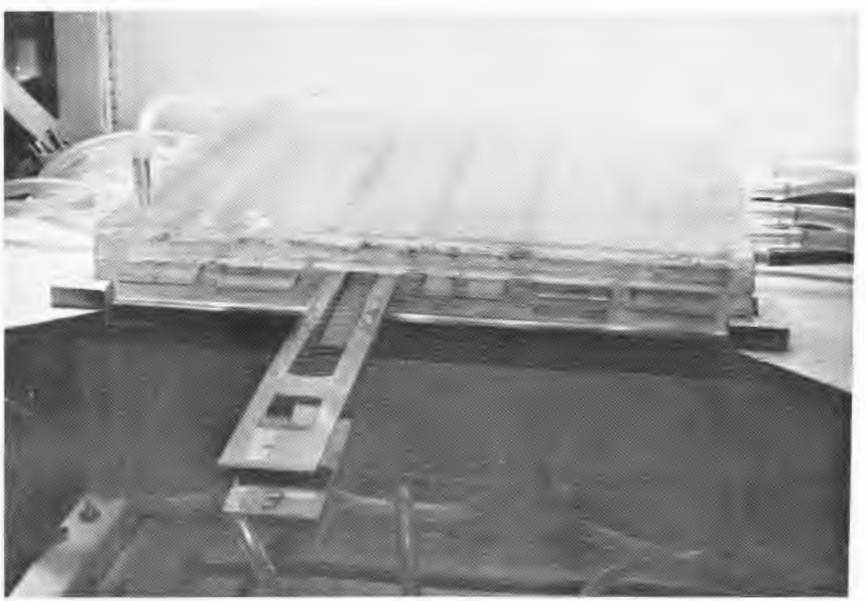

Figure 3. Six preconditioning chambers with a common water jacket. Plastic frames are protruding from the third chamber from the left. The other five chambers have the plastic frames already inserted.

CER remained stable to a flow rate of 2.4 l/min., but at rates faster than 2.5 l/min., CER decreased steadily. Wolf et al. (1969) using orchardgrass, and Nelson et al. (1974) using fescue obtained similar responses for attached leaves.

Leaf Harvesting and Sectioning

Our system uses leaves excised from plants wherever they are grown. After excision, the leaves are surrounded by wet paper towels and transported to the laboratory in an insulated chest. In the laboratory, just before CER measurement, the leaves are cut or sectioned to fit the CER chamber. Primarily, we have studied two species, maize and reed canarygrass. For maize we use a rectangular punch (1.5 x 12.0 cm), and for reed canarygrass we cut the leaves a given length and measure the average width to compute area of the leaf section. One or more leaf sections may be inserted into the CER chamber, which, in our model, is 25 cm long.

To determine the length of time that excised maize leaves maintained their original CER, we measured the CER of leaf sections from an inbred (A619) and a hybrid (A619 x A632), both grown in a growth chamber. Results (Figure 4) indicated that leaf sections could be measured from 1 to 4 hr after excision without appreciable differences in CER. Later, in field experiments we observed reduced CER if leaves were measured before 1 hr after excision. Excised leaves of reed canarygrass were measured as long as 5 hr after excision, with no decrease in CER. The senior author has kept alfalfa leaves floating on water for 8 hr with no significant decline in CER.

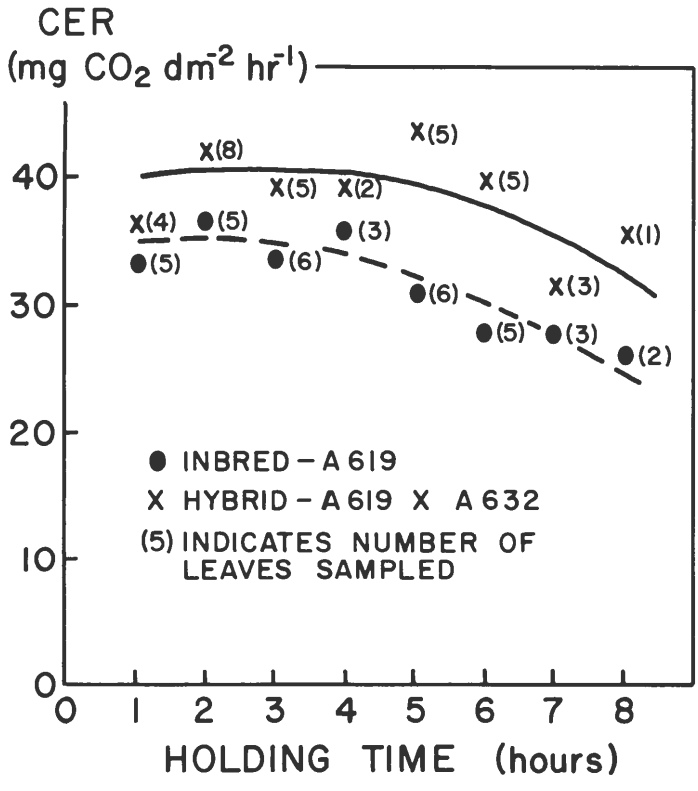

Figure 4. Effect of time after leaf excision on CO_2-exchange rate (CER) of maize leaves.

Reliability

Thirty-six field-grown maize inbred lines from Iowa Stiff Stalk Synthetic were measured for CER before tasseling. CER (average of eight leaves from each line) ranged from 20.2 ± 5.3 to 70.6 ± 2.8 mg CO_2 dm^{-2} hr^{-1}, with a mean of 46.4 ± 5.7 mg CO_2 dm^{-2} hr^{-1} (C.V. = 17.6%). This compares favorably with rates recorded in the literature (Heichel and Musgrave, 1969; Duncan and Hesketh, 1968). In reed canarygrass, the CER of 22 clones (four measurements per clone) growing in the field was measured. Rates ranged from 12.5 to 31.4 mg CO_2 dm^{-2} hr^{-1}, with a mean of 20.9 ± 1.3 mg CO_2 dm^{-2} hr^{-1} (C.V. = 12.1%). These rates are similar to those measured on other cool-season forage grasses (Nelson et al., 1974).

Also, three field-grown soybean *[Glycine max* (L.) Merr.*]* lines were sampled at beginning bloom. Twelve leaves per line were sampled and cut into strips (1.5 cm wide) parallel to the midrib. CER of these lines ranged from 21.4 ± 1.0 to 27.9 ± o.8 mg CO_2 dm^{-2} hr^{-1}, with a mean of 24.5 ± 1.3 mg CO_2 dm^{-2} hr^{-1} (C.V. = 13.4%), which compares favorably with rates recorded in the literature (Dornhoff and Shibles, 1970; Curtiss et al., 1969).

We made a direct comparison of CER for excised and attached leaves of four maize inbreds selected for low and high CER. The plants were grown in 25-cm-diameter clay pots during late summer, 1974. CER was measured on the youngest, fully expanded leaf at about the tenth leaf stage. The attached leaf chamber was similar to chambers used by Hansen (1970) and Austin and Longden (1967) and was made to clamp on both sides of the leaf so that leaf tissue was positioned between rubber gaskets. The air stream in the chamber was divided and passed both over and under the exposed portion of the leaf. Chamber cross-sectional area, leaf area measured, light intensity at leaf surface, air temperature, and flow rate were the same in both attached and excised leaf chambers. The area of the leaf measured by the attached leaf chamber was excised, and within 4 hr was again measured for CER.

Only 10 measurements were taken because it was difficult to obtain an airtight seal with the attached leaf chamber, and because, after the chamber was sealed, 20 to 40 min were required for CER to reach equilibrium. Eight of the 10 measurements agreed within 10% (Figure 5). One would select the same two plants with the highest and with the lowest CER with either method of measurement.

Statistical Designs

We used a square lattice design (blocked on leaf-excision sampling times) for our CER measurement experiments. This design permitted correction if samplings were different. If other statistical designs are used, it would be advantageous to block on sampling time whenever possible.

DISCUSSION

Our method eliminates many of the factors that have made leaf enclosure and CER measurement difficult. Leaf sections are punched or cut from the leaves and easily inserted into and withdrawn from the chambers. The system uses outside air that is not dried before entering the infrared gas analyzer.

The method is fast because leaf sections are preconditioned before being placed in the CER chamber. Depending upon how long it takes for an individual leaf section to reach CER equilibrium, one can measure 100 to 240 leaf sections in 8 hr.

Our system is convenient because all measurements are made under standard conditions in the laboratory, there is no periodic movement of equipment, and only two persons are required—one to collect excised leaves and one to measure CER. Leaves can be collected wherever the plants are growing, even though an electrical source is not accessible, and they can be sampled under most weather conditions. We even measured leaves at night and observed no evident reduction in CER (but a longer preconditioning time was required).

A disadvantage of our method and other methods using excised leaves is that any immediate direct influence of the plant on leaf CER is not measured. Also, if leaf excision influences some lines, but not others, actual CER would be biased. Because most species measured to date (Pearce et al., 1969; Wilson et al., 1969) and the species measured in our studies had CER's similar to those of attached leaves, there is little evidence to support the latter point.

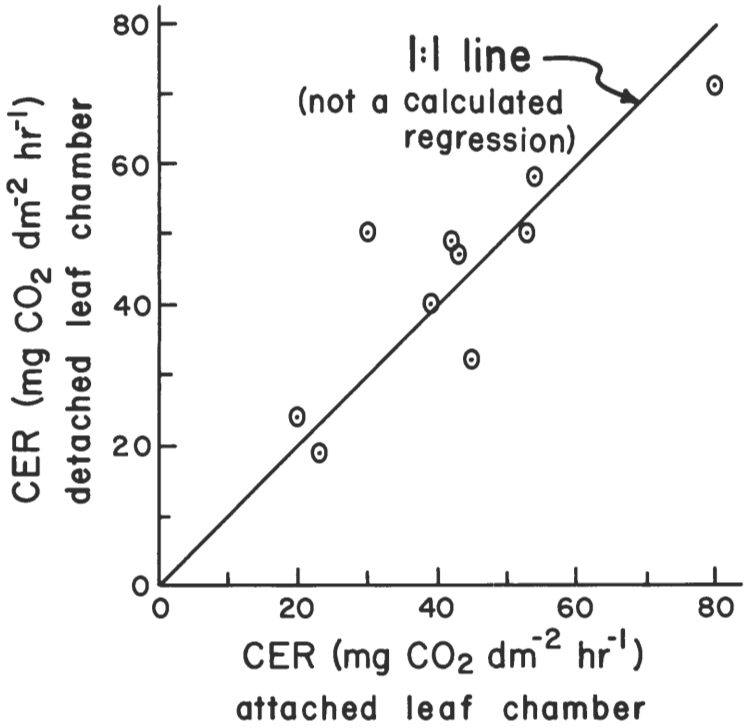

Figure 5. Comparing the CO_2-exchange rate (CER) of attached and detached maize leaves. Each point illustrates the CER of the same leaf when first measured attached, then detached and measured with our system.

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OBJECT PREFERENCE AND RESULTING MOVEMENT BEHAVIOR OF THREE-TO-SEVEN-YEAR-OLD CUSTODIAL AND TRAINABLE RETARDED BOYS

Darlene K. Conover[1]

ABSTRACT. Eleven institutionalized retarded boys were exposed to five objects (ball, blocks, climber, inner tube,wagon) to determine object preference and movement behaviors exhibited. Data collection consisted of (1) *study of object familiarization* to introduce each subject to each object to reduce effects of familiarity and novelty, and (2) *study of object preference* to determine which object was most preferred when all five objects were presented simultaneously.

Major findings showed that these subjects, as a group, displayed no object preference; however, individual subjects did demonstrate a preference. A significant positive correlation existed between motor age and time spent with the ball and total time spent with all objects combined. A significant positive correlation also existed between IQ and time spent with wagon. Movement behaviors most prevalent were: head—resting; hands—manipulating; arms—holding, lifting, pushing; legs—walking; trunk—sitting. Movement behaviors occurring for the greatest length of time were inactive and sedentary in nature.

INTRODUCTION

Public institutions for the retarded are plagued with the triple problem of overcrowding, understaffing, and underfinancing. As a result the amount, pattern, and type of stimulation available is often less than desirable. It is possible that one of the reasons retardates engage in stereotyped behaviors is to raise the level of stimulation. Significant relationships have been found between stereotypy and manipulative objects, manipulation of environment, and object preference (Berkson & Davenport, 1962; Berkson & Mason, 1963). The importance of early motor experience in providing the foundation for future development and learning is discussed by Hebb (1965). As motor activity is vital for cognitive development, experiences with objects and stimuli are essential. Inadequate sensori-motor experiences can result in either delayed or impaired development or both (Johnson & Medinnus, 1969). In light of what is known of institutional environments, growth and development, and intellectual functioning, provisions must be made to enhance the development of the retarded to develop more fully what potential they have. Such provisions include reshaping nonstimulating environments.

The purpose of this study was to determine whether objects placed in an environment will evoke movement behaviors. As no research has been done regarding object preference with preschool, trainable, retarded boys, an additional purpose was to determine which objects were preferred. Also, the types of movement behaviors evoked by the objects were recorded and studied to determine which body parts were predominantly involved.

METHOD

Subjects

Eleven boys between the chronological ages of 39 to 83 months (M-64) wereselected for the study. Subjects of only one sex were selected because of significant differences shown

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between sexes in regard to vigorousness of play (Witty & Beaman, 1933), object preference (Goldberg & Lewis, 1969), and attention span (Shacter, 1933). All subjects were ambulatory and displayed no severe gross motor defects. They resided in the same residential institution and were exposed to the same environmental conditions. The 1960 Revision of the Stanford Binet Intelligence Scale, Form L-M, produced adjusted IQ scores ranging between 17 and 49, with a mean of 29. The Denver Developmental Screening Test (Frankenburg & Dodds, 1967) was administered to determine functioning level of the subject. Mean scores, in months, for each sector were: Gross Motor, 21; Fine Motor, 20; Language, 13; Personal-Social, 24.

Objects

Five objects were selected for the study on the basis of growth and developmental needs of children (Espenschade & Eckert, 1967; Illingworth, 1972), results of play preference, and color studies (VanAlstyne, 1932; Jones, 1939; Gramza, 1969). The multicolored ball, 8½" in diameter, was made of durable plastic. Four blocks, 12" by 6" by 4", made of sturdy cardboard were included. The climber consisted of a small ladder with two steps and a platform 18½" by 17". Two railings, 12" above the platform, served as hand supports. A black, heavy-duty innertube from a deluxe truck-tire was included. The wagon, made of durable plastic, consisted of a bed 36" x 16", a 25-inch handle, and four ballon-type wheels, each of which was 8" in diameter.

Testing Room

The testing room, 15' 10" x 18' 9", was completely empty during the testing sessions except for the subject and the object to which he was exposed. All objects and pictures were removed from the walls to eliminate any external distractions. Two doors provided access into the room. The same door was used for both bringing subjects in and removing them at the close of the testing period. A special door was constructed and replaced the second door for purposes of observation. This consisted of a piece of ½"plywood, 35¾" x 83¾", which fit snugly into the doorjamb. A plastic viewing window, smokey in color, was built into the door. The area behind the door was darkened so that subjects were unable to see the observer.

Procedure

Data collection was divided into two major portions: study of object familiarization and study of object preference. Object familiarization was conducted to introduce each child to each object to reduce any effects from familiarity and novelty. Order of subjects and objects was determined on the basis of a Latin Square arrangement. Five familiarization periods were conducted, with each subject being introduced to only one object during each period. Each subject was tested at approximately the same time each day. The subject was brought into the room, placed about 18" from the object, and was told he could play with it. Each object was always placed in the same position in the center of the room (Gramza & Witt, 1969). No teaching or demonstrating was done and no suggestions were given as to how to play with any object. Each subject was left alone in the room with the object for a period of 5 minutes, during which time his behavior was recorded into a cassette recorder.

The study of object preference was conducted to determine which object, if any, was most preferred by the subjects when presented with all objects simultaenously. The placement of the objects and the point of entry of subjects between objects was determined on the basis of a counterclockwise rotation of objects. This procedure was used to reduce any possible built-in bias due to the location of objects and point of entry, and to eliminate any contamination from the familiarization study. The objects were placed in a circular formation in the center of the room and rotated with each subject. No teaching or demonstrating was done. Each subject was left alone in the room for a period of 8 minutes, during which time his behavior was recorded.

RESULTS AND DISCUSSION

One purpose of this study was to determine if the presence of objects would evoke movement behaviors. In both the study of object familiarization and object preference,

movement behaviors were evoked by each subject. It should be noted that subjects spent less than 50% of the time available with the objects per se. This may be attributed to (1) short attention span characteristic of low functioning retardates, (2) inexperience in playing with objects, (3) lack of human interaction, (4) preference for other acts (some subjects preferred to do nothing, look about the room, or play with clothing rather than interact with objects). It should also be noted that not every object evoked movement from every subject. As shown by Thompson (1960), not all objects possess the same stimulus properties for all subjects.

It was hypothesized that this group of subjects would show object preference when presented with a group of selected objects. The data from the study of object preference were subjected to a univariable analysis of variance on the basis of time spent with each object. There was no significant difference between subjects ($F = .641$, 10/40 df, $p > .05$), and none between objects ($F = .239$, 4/40 df, $p > .05$). As no significant difference existed between the mean times spent with the various objects, this group of subjects does not show object preference on the basis of time; thus, the hypothesis must be rejected. The data from the study of object preference were also subjected to a univariable analysis of variance on the basis of frequency of contact with each object. There was no significant difference between subjects ($F = 1.477$, 10/40 df, $p > .05$), and none between objects ($F = .738$, 4/40 df, $p > .05$). The hypothesis must also be rejected on the basis of frequency of contact.

Two possible explanations may be offered for the lack of group preference. If the subjects had been shown how to play with each object, this preference might have been affected. Secondly, although subjects are all institutionalized retardates, they do show unique personalities with individual likes and dislikes.

Demographic Data

Chronological age, motor age, and IQ of the subjects were each correlated with the total amount of time spent with each object and with the total amount of time spent with all objects combined. In study of object familiarization, a significant correlation ($r = .6691, > .05$) existed between motor age and total time spent with all objects. In object preference a significant correlation ($r = .7717, > .01$) existed between motor age and total time spent with all objects. Several explanations may be offered: (1) the higher the motor age, the better the coordination; hence, time available for involvement may be better utilized; (2) with better coordination, involvement with objects is facilitated; and (3) the higher the motor age, the greater variety of possible movement behaviors.

A significant correlation ($r = .6491, > .05$) was found between motor age and time spent with the ball. Of all objects included the ball has the greatest mobility, is easiest to move, and maintains its momentum longest. Subjects with a higher motor age can maintain involvement for a longer period of time as it is easier for them to impart momentum initially, then respond to the movement as the ball rebounds from the walls and floor.

Significant correlations (Study of Object Familiarization: $r = .8507, > .001$; Study of Object Preference: $r = .6628, > .05$) were found between IQ and time spent with the wagon. Of all the objects the wagon was the most complex, had the greatest number of moving parts, and presented the most opportunities for combining various movement behaviors. It appears that play with the wagon requires a higher IQ than with the other four objects. That it takes a certain amount of intelligence to coordinate the locomotion of the body with the locomotion of a wheel toy is consistent with the findings of Jones (1939).

Utilization of Body Parts

Percentages were computed for the amount of time each body part was utilized with each object. In both the study of object familiarization and object preference, the body part used the greatest percentage of time was the hands. The body part next most commonly used was the arms. The part least used was the head. Considering all five objects, movement behaviors most exhibited by the subjects included in this study were: resting with head; manipulating with hands; holding, lifting, and pushing with the arms; walking with the legs; and sitting with the trunk. The movement behaviors most displayed by the subjects were somewhat sedentary and allowed for long periods of simple and sustained contact with the objects. The behaviors displayed by the subjects during involvement with objects are characteristics of their passive response to the environment in general.

One way in which to enhance the development of the retarded is to expose them to objects that have appropriate stimulus properties. It should be noted that merely to surround the retarded with objects in a setting devoid of human interaction and with no instruction in the use of the object is insufficient to establish stimulating and functional environments.

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ASPECTS OF THE FLORA OF ADAK ISLAND, ALASKA: VASCULAR PLANTS

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ABSTRACT. Adak Island, Alaska, is located in the central Aleutian Islands. From May through September, 1974, I collected representatives of the vascular plant flora of the northern half of the island. The taxa in these collections are listed according to habitat and family, with a brief discussion of the habitats and of the plants that are outside their known distribution ranges.

INTRODUCTION

The first plant collection in the Aleutians was made by Carl Meck in 1790-91. Since that time up to 1940, numerous other collections of varying sizes were made in the Aleutians. These are cited by Hultén (1960). Since 1940, other collections and studies have been made (Porsild, 1944; Walker, 1946; Eastwood, 1947; Kazmaier, 1968; Shacklette et al., 1969; Amundsen, 1972) in the Aleutians. No major collections have been made on Adak Island since 1932 when Hultén collected plants from Adak. From 16 May through 26 September 1974, I collected as many different species of vascular plants as could be located on the island. From lack of roads and inaccessibility of the southern half of the island, most of the collecting was done on the northern half. During August a helicopter was taken to the southern half of the island. On this trip no plant species were noticed different from those collected on the northern half of the island.

Plants in the collection were identified, and the first set of plants was deposited in the Anderson herbarium at Iowa State University. Partial replicate sets are being sent to the Brigham Young University herbarium and to other herbaria around the United States by Dr. Richard Pohl of Iowa State University.

In the Appendix is a list of the vascular plants collected on Adak Island. The list is arranged according to families, following the nomenclature and arrangement in Welsh (1964). (An exception to this is *Elymus* X *aleuticus* (Hultén) Bowden, which was identified from the description in Hultén (1936). An "I" before the scientific binomial indicates that the plant is believed to have been introduced and probably is not native to Adak Island. A "W" indicates that Adak Island is within the known species distribution for that species according to Hultén (1968, 1973), but has not been collected previously on Adak. An "A" indicates a previous collection on Adak Island, according to the range maps in Hultén (1968). An "O" means that Adak Island is outside the known distribution range.

Numerals following the names indicate habitats in which the plants were found, and correspond to the following habitat types:

1 Submerged in ponds and lakes in approximately 0.1-1.2 m of water.
2 Near edges of lakes and in ponds in approximately 3-10 cm of water.
3 In lawn and beside buildings on Bering Hill.
4 Wet areas in shady ravines and along stream banks and edges of ponds.
5 Wet areas.
6 Hillside slopes.

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7 Dry slopes.
8 Mountain side slopes (elev. ca. 80-610 m).
9 Rocky soil.
10 Rocky and sandy soil along edge of parking lot, roadsides, and disturbed areas.
11 Sandy soil.
12 Sandy soil along beach.
13 "Adak National Forest" on hillside slope.

LOCATION AND SETTING

Adak Island, Alaska, is located in the Andreanof Group of Aleutian Islands at latitude N51.45 and longitude W176.40. The nearest continental land masses are mainland Alaska—approximately 1,130 km to the northeast, and eastern Siberia—approximately 1,130 km to the northwest. The island of Adak is about 45 km long and 35 km wide at its widest part (NWSED, 1973).

The terrain of Adak Island is very rugged and mountainous, and is composed of volcanic material. The highest peak, Mount Moffett, is approximately 1.2 km high and located on the northwest part of the island. Minor earthquakes are not unusual on Adak, earth tremors occur quite frequently, and active volcanoes are in the area. Mount Sitkin (elev. 1.74 km), located on Great Sitkin Island 40 km to the northeast, erupted on 19 February 1974. Steam and smoke can also be seen occasionally from Kanaga Volcano (elev. 1.3 km) on Kanaga Island 35 km to the west.

The surficial material of Adak Island is composed chiefly of volcanic ash. This, plus the short growing season and low average summer temperature, has retarded tree and other plant growth on the island. Dwarf willows, herbaceous plants, grasses, mosses, and an abundance of wild flowers in the summer comprise most of the island's vegetation. The very irregular coastline varies from broad beaches to sheer sea cliffs. With the exception of the "Adak National Forest," the island is completely treeless with tundra-covered lowlands and numerous small lakes and streams.

The approximately 5,000 military personnel on Adak Island live primarily on the northern one-third of the island at various military installations. Except for those federal employees associated with the naval base, there are no civilian inhabitants on the island.

There are approximately 202 km of roads on Adak, most of which are on the northern one-third of the island. There are no maintained roads on the remainder of the island. Scattered over much of the northern half of the island are remnants of World War II, including rusting and decaying Quonset huts, wooden shacks, oil drums, piles of junk metal, rows of barbed wire fences, and wooden walkways and stairs that lead over the rolling landscape to nowhere because the buildings at the end have since blown away (Carlson, 1972)(Fig. 1).

CLIMATOLOGY

The climatic record for Adak Island is based on records covering a 24-year period and taken by personnel at the Naval Weather Station located on the western side of Kuluk Bay at an elevation of 6 m. The western and central part of the Aleutian Islands, in which Adak Island is located, is among the stormiest regions of the world. Storms occur in any season but are most numerous and severe during winter. Adak Island is cooled by the Bering Sea and warmed by the Kuroshio or Japanese Current, which flows in a northeasterly direction. Since the Kuroshio extension flows south of the Aleutian Islands, the sea temperatures around Adak range from 0-5°C in January to March and to near 10°C in August. The cold winds from Siberia and the ocean currents flowing down from the Bering sea meet the warm air masses and ocean currents just south of the Aleutian Islands and this interaction produces winds of high velocity, dense fog, rain, mist, and snow (Baldwin, 1973; NWSED, 1973).

Because of the warm sea temperatures surrounding Adak, a rather mild climate for this northern latitude is encountered. The mean temperature ranges from 1°C in February to 11°C in August. The mean daily range is 6°C or less in all months and the mean annual range is only 6°C. The highest recorded temperature for Adak Island is 24°C (75°F) on August, 1956; the lowest recorded temperature was -16°C (3°F) in January, 1963 and February, 1964. However, the frequent occurrence of high winds with temperatures below 5°C in the winter requires that the windchill factor be considered. Both summer and winter storms are usually

Figure 1. World War II Quonset huts and wooden walkways.

Figure 2. Fishermen near Finger Bay with hummocky hillsides in the background.

accompanied by 70 to 110 km/hr winds, with the highest peak gusts being recorded in March, 1954 of 202 km/hr (109 knots). Although mean annual precipitation is not excessive (168 cm), precipitation in some form occurs approximately 264 days out of the year and the sky is clear less than 2.2% of the time in all months. The mean relative humidity is 84% (NWSED, 1973, 1974[2]).

The effect of the mountainous terrain of Adak Island on surface winds is significant and results in a blocking or funneling effect. During strong northwesterly air-mass flows, the wind becomes extremely gusty. This is especially true in fall and winter when a northwesterly flow is usually associated with squally weather. The prevailing west wind on Adak Island is caused by the location of the Aleutian low in winter and North Pacific high in summer. In general, Adak Island does not have an Arctic climate, nor does it have the extreme hours of daylight and darkness that most of Alaska does. On the shortest day of the year, December 21, sunrise is at 0852 and sunset is at 1637. On the longest day, June 21, the sun rises at 0528 and sets at 2225 (NWSED, 1973).

During the summer of 1974, new grass shoots and plants were first starting to appear near the end of March from the heavy grass mats of last year's growth. By the end of May grasses and sedges had grown enough that the hillsides were beginning to turn green and a few of the very early wildflowers were beginning to bloom. By the end of July wildflowers were approximately at their peak; however, many of the earlier species were through anthesis—even *Lupinus nootkatensis* was starting to produce seeds. By the end of August most of the wildflowers had finished blooming and many had gone to seed. The grasses were also starting to turn brown in areas. By the end of September only a few wildflowers were still blooming in sheltered places. The first snows down to approximately the 610-m elevation level on Mount Moffett occurred the first week of October; by the last week of October, snow was staying on the ground near sea level.

FLORA

As noted previously, Adak Island is completely devoid of trees except for the "Adak National Forest." This is a small stand of approximately 20 Sitka spruce trees *(Picea sitchensis)* that were planted by Navy personnel in 1951 on the hillside just north of the Naval Facility located on the western side of Kuluk Bay. These trees are now only about 3 to 4 m high. In the protection afforded by them is a small stand of *Salix barclayi* or Barclay willow. These are now approximately 1.5 m tall. According to Hultén (1968), neither of these species has been reported for Adak Island. Except for four other known stands planted on Amaknak and Expedition Islands in Unalaska Harbor and on Amchitka and Shemya Islands in the western Aleutians, *P. sitchensis* is limited to the southern and southeastern coasts of Alaska (Walker, 1945; Hultén, 1968; Shacklette et al., 1969; Amundsen, 1972). *Salix barclayi* extends out into the Aleutian Islands but only as far as Unalaska Island. Whether it was transplanted as roots or seeds in the soil accompanying *P. sitchensis* or whether it has since migrated farther west is unknown.

In contrast to most study areas the vegetation of Adak Island does not fall into well-defined plant communities in general except for the beach community; the pond, lake, and stream community; and the disturbed area community along roadsides and around buildings. The vegetation of the remainder of the island appears as a continuum based on the moisture present in land areas, which varies from wet lowland areas to dryer hillside slopes. But even the hillsides and mountain sides are not in themselves uniform, since they are often very hummocky (Fig. 2) with many ravines, depressions, ephemeral pools (Fig. 3), and small lakes on them. Here, many of the ecotones separating the communities are not well defined and can be very broad. Hence, exact delimitations of the various communities are necessarily arbitrary.

DISCUSSION

In general, most of the larger lakes with rocky bottoms lack submerged or emergent plant life. Only in the smaller, more shallow lakes and ponds, which have bottoms covered

[2] Naval Weather Service Environmental Detachment (NWSED). 1974. Monthly climatological summary for 1974. Naval Station, Adak, Alaska. 12 pp. Unpublished.

with approximately 10-15 cm of very loose silt and mud, is aquatic plant life found (Fig. 4).

Of particular interest in this habitat are edges of the lakes and ponds, since they are usually straight sided along the banks instead of gradually sloping. At the base of the hillsides around a lake, there is usually a relatively level band of land at the edge of the water. This can vary in width from 0.2-3 m.

Shacklette et al. (1969) give two explanations for this. The first is that during the winter, if the air temperature drops rapidly below freezing while gale-velocity winds are blowing, water is frozen in midair from the lake surface and dropped on the leeward side of the lake. The pressure exerted on the vegetation mat of the largely unfrozen bank pushes the mat up and out to form the elevated rims characteristic of many lakes. Another process is that a rise in temperature during winter causes the ice on lakes to expand and push against the banks or override them. Often this ice contains much sediment that was suspended in the water when it froze; this is then deposited on the bank when the ice melts.

During winter and summer of 1974 another factor was observed to be taking place. At the mouth of the streams emptying into the lakes, alluvial fans were observed to be building up. As water ran or seeped from the hillsides, much of the suspended organic matter was also deposited at water's edge. Eventually, this would account for buildup of the level strips of land around the lakes. Vegetation soon covers them and holds more of the newly deposited soil. The vegetation grows so abundantly on Adak Island that often it extends out over the edges of the banks and roadside cuts. Eventually the weight is such that a part of the bank starts to break off and separate, since the water saturated soil is so poorly bound together. This is aided in winter by expansion and contraction of ice in the cracks, and in summer by wave action undermining the banks when the water level is lower in the lake. As these pieces of the bank break off, the characteristic straight sides and sharp dropoffs are formed (Fig. 5).

Figure 3. *Ranunculus aquatilis* in small pool.

Figure 4. Shallow lake with *Hippuris vulgaris* along edge.

Figure 5. Vegetational overhang and separation along a shore bank.

According to Hultén (1968) all plant species found growing submerged in ponds and lakes have been recorded for Adak Island or assumed to be present from locations on nearby islands except for two species. These are *Limosella aquatica* and *Potamogeton pectinatus* (fennel-leaf pondweed). *L. aquatica* occurs over much of North America, Europe, and Asia, but according to Hultén (1968) only has a very widely scattered distribution in Alaska and the Aleutians. It now appears to be continuous in the central Aleutian Islands. *P. pectinatus* is far out of its range, the nearest collections being southern Alaska and the Kamchatka Peninsula. This may have been introduced by military operations sometime in the past.

Collection of two sedges from shallow water and wet areas extends the range of both westward in the Aleutians. Hultén reports *Carex aquatilis* (water sedge) and *Eriophorium angustifolium* (tall cottongrass)as far west as Umnak and Unimak Islands, respectively.

Within the wet lowland areas were found many different small habitats, all having one thing in common: abundant water. These included drainage areas where hillside streams reach a relatively flat area and spread out before descending the next slope, marshes, stream banks, ravines, pond edges, and small meandering drainage areas or bogs where *Sphagnum* sp. is very predominant and forms a thick spongy layer. Many of these valleys and depressions are small and limited to 2-3 m width; others can be 100-200 m wide with numerous ponds and shallow lakes underlain by peat. In the wetter areas, besides *Sphagnum* sp., sedges and lichens are prominent, with grasses in the dryer parts. Wildflowers are very abundant during the growing season, the common ones being, *Aconitum maximum* (monkshood),*Anemone narcissi-flora, Epilobium alpinum* var. *behringianum* (alpine willow-herb), *Geum calthifolium* (caltha-leaf avens), *G. pentapetalum* (low avens), *Heracleum lanatum* (cow parsnip), *Montia sibirica* (Siberian spring-beauty), *Parnassia kotzebuei*(Kotzebue grass-of-Parnassus),*Pedicularis chamissonis* (chamisso lousewort), *Pinguicula vulgaris* var. *macroceras* (bog-violet), *Streptopus amplexifolius* (cucumber-root), and several species of Orchidaceae (Figs. 6, 7, 8, 9).

Of the plants found in these habitats, five species are outside their known distribution range, including *Eriophorum angustifolium,* which has been already discussed. *Eleocharis quinqueflora* is known from the Kamchatka Peninsula and interior Alaska, with no known closer locations. *Juncus falcatus* var. *stichensis* is found along the northwest coast of North America and the islands south of the Kamchatka Peninsula, with only a scattered distribution in the Aleutian Islands. It now appears to be more continuous through the Aleutians. *Listera convallarioides* (broad-leaved twayblade) is found in northern North America and occasionally in the Aleutians. Again it now appears to be more continuous. *Ranunculus occidentalis* var. *brevistylis* (western buttercup) is found along the northwestern coast of North America, with the closest location being in southern Alaska. Probably it has been introduced on Adak by military operations. This is the first known collection from the Aleutians.

Included in the wet lowland areas are depressions resulting from human influence on the area. These include the sites of former Quonset huts from World War II, roads, and other construction areas. Anywhere the tundra has been removed or disturbed for some time, water rapidly fills the depression. This results in dissolution, subsidence, or compaction of the peat below and often a small pond is formed (Amundsen & Clebsch, 1971). The best examples of these are former Quonset hut and building sites and foxholes from World War II on the hillsides. Many of the Quonset huts had soil piled around the bases for camouflage and insulation. After the building collapsed or was blown away, these ridges of soil restricted drainage such that plants characteristic of wet areas are found here. Many of the shallow foxholes dug during World War II now contain an abundant growth of *Sphagnum* sp., other mosses, and liverworts. Some of the deeper holes of approximately 1 m deep are now half filled with water much of the year. Other foxholes which are on steeper or better-drained hillside slopes are not filled with water and sometimes have a few plants growing in their bottoms, including *Lycopodium clavatum* (running clubmoss), mosses, and *Cicuta douglasii. C. douglasii* was not collected and is a tentative identification from a color slide only. If *C. douglasii* was on Adak, this is the first time it has been reported from the Aleutians. It has probably been introduced. Slowly the tundra (especially the *Sphagnum* and club mosses) is overgrowing the edges, but many more years will probably be required to fill them in since many are still very straight sided with little erosion or washing taking place in them.

Of special interest in the lowlands and wider valleys are distinctive conical mounds up to 1.5 m high consisting mainly of *Sphagnum* moss. These mounds are slightly drier and better areated than the surrounding region and have plants more characteristic of hillside slopes growing on them. These include *Empetrum nigrum* (crowberry), *Cornus suecica* (Swedish

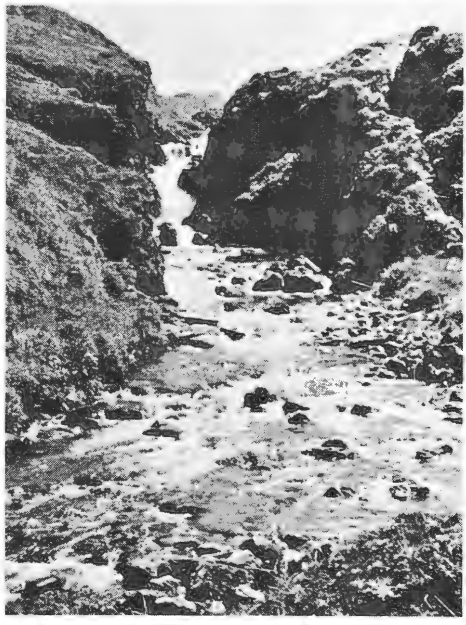

Figure 6. Typical mountain stream.

Figure 7. Ravine with *Streptopus amplexifolius, Ranunculus occidentalis, Erigeron peregrinus,* and *Athyrium filix-femina.*

Figure 8. *Leptarrhena pyrolifolia* growing in wet bog area.

cornel), *Loiseleuria procumbens* (Alpine azalea), club mosses, lichens, a few liverworts, and also *Calamagrostis nutkaensis* (Pacific reedgrass) mainly on the sides.

When I excavated one of the mounds on 7 October 1974, it consisted of a surface layer of approximately 4 cm of crowberry, lichens, liverworts, and *Sphagnum* moss. Below that, the rest of the approximately 1 m high mound consisted of *Sphagnum* in increasing degrees of decomposition with stems and roots of *Empetrum nigrum* and *Loiseleuria procumbens* running through it. Excavation was stopped when soil was reached.

As these mounds grew in size, various species of birds including bald eagles, ptarmigans, and sea gulls started using them as resting areas and vantage points, especially if they overlooked a lake or were along the coast. As noted by Shacklette et al. (1969), eventually the mosses and lichens are replaced by grasses and the mound eventually breaks down.

Also of interest is the location or habitat in which *Rhododendron camtschaticum* ssp. *camtschaticum* (Kamchatka rhododendron) was found. It was found in only one location on the steep side of a ravine and consisted of a small patch 0.5 m across. This seems to be very characteristic for it in the Aleutians. Shacklette et al. (1969) describe its occurrence on Amchitka Island to be in small patches of heath on steep slopes near the mountain tops.

The next type of vegetational pattern includes the dryer hillside slopes (Fig. 10). These usually are covered by grasses, crowberry, *Sphagnum*, club mosses, flowering plants, and *Salix arctica* (Arctic willow). *Salix arctica* (Fig. 11) is a dwarf shrub,which grows horizontally along the tundra surface with only the ends of the stems directed upward 5-10 cm. The stem and roots are very twisted and often the roots lie exposed on the surface along with the stems. The grasses include *Calamagrostis canadensis* (bluejoint), *C. lapponica* (Lapland reedgrass), *C. nutkaensis* (Pacific reedgrass), *Elymus* X *aleuticus* (Fig. 12), *E. mollis* (dunegrass), *Festuca rubra*, *Phleum alpinum* (Alpine timothy), *Poa arctica* (Arctic bluegrass), *P. trivialis* (rough bluegrass), and *Trisetum spicatum* (downy oatgrass).

As one proceeds up the hillside slopes and mountain sides, the vegetational layer becomes less dense. The tops of many of the hills and most of the mountains are primarily exposed rock outcroppings with little plant life on them (Fig. 13). The plants present consist of crowberry, lichens, moss, *Salix arctica*, and only a scattered culm or clump of grass (Fig. 14). At the very top of most of the mountains such as Mount Moffett (Fig. 15), no plant life can

Figure 9. *Petasites frigidus* growing in wet bog area.

Figure 10. Hillside slope with *Arnica unalaschcensis, Erigeron peregrinus,* and *Pedicularis chamissonis.*

Figure 11. *Salix arctica.*

Figure 12. *Elymus* X *aleuticus.*

be observed and only gravel-strewn or rocky patches with rocky outcroppings and peaks are found.

Of the plants found in this type of habitat, six species are outside the known distribution range. *Eriophorum angustifolium* has been discussed relative to lake and pond edges. *Arenaria lateriflora* (blunt-leaved sandwort) is known to occur in most of northern North America, Asia, and Europe. It also extends both east and west into the Aleutian Islands but is unknown in the central islands. It probably is continuous through the Aleutians.

Calamagrostis lapponica (Lapland reedgrass) is also found in much of the northern North America and Asia. Since the nearest known locations are southern Alaska and the area around the Bering Strait, *C. lapponica* was probably introduced on Adak Island by military operations. However, this is the first-known collection of it in the Aleutian Islands. Although *Empetrum nigrum* is known to grow on Adak Island, ssp. *hermaphroditum* is known only as far west in the Aleutians as Unalaska Island. From its known distribution, one is uncertain whether it has migrated to Adak Island or has been introduced. It may occur on more islands between Adak and Unalaska. *Poa trivialis* (rough bluegrass) according to Hultén (1968) is an introduced weed in Alaska. Its distribution, though scattered through the Aleutians, is now nearly continuous. The last new species in this group, *Salix polaris* (Polar willow), is known from the Kamchatka Peninsula, northern and southeastern Alaska, and only one island (Amchitka) in the Aleutians (Hultén, 1960, 1968).

The last naturally occurring and undisturbed community is the beach community. The shoreline of Adak is primarily of two types. Many parts have sheer, rocky sea cliffs 30 m or more high, strewn with boulders at the base and with very little plant life. Other parts of the coastline consist of sandy beaches with sand dunes up to about 3-4 m high. On the sandy beaches the first plant one encounters is *Arenaria peploides* (sea-beach sandwort) in a band above the high tide mark. In some places intermixed with or just above this band is found *Equisetum arvense* (meadow horsetail). Along the top of the dunes and higher parts of the beach is a dense band of *Elymus mollis* (dunegrass).

On the landward side of the dunes and often between dunes, *Senecio pseudoarnica* is found in great abundance. Farther inland, but where the soil is still sandy and dry, *Achillea millefolium* (yarrow), *Barbarea orthoceras* (wintercress), *Epilobium alpinun* var. *behringianum* (Alpine willow-herb), *Lathyrus japonicus* (beach pea), and *Rumex acetosella* are found.

Of the beach-community plants, only one species, *Rumex acetosella*, is unknown in the central Aleutians. According to Hultén (1968) it is found across much of central North America, central Asia, and northern and central Europe. It also occurs in both the eastern and western Aleutians as far west as Unalaska and as far east as Attu Island. It may have migrated to Adak or it may have been introduced, since Hultén describes it as an introduced weed along the southern coast of Alaska.

The last group of plants can be characterized as those found in disturbed areas (Fig. 16) and those that were introduced. Among the first plants to re-establish itself again in a disturbed area is *Epilobium angustifolium* (fireweed). Fireweed is very common on Adak Island along roadsides, edges of parking lots, and where "tundra slides" have occurred and exposed bare soil.

Many of the introduced plants were probably introduced on construction equipment through military operations of building and road construction, and probably in grass seed that was used to try to establish lawns around the buildings on the Naval Station. Many of these such as *Bellis perennis* (European daisy), *Trifolium pratense* (red clover), and *T. repens* (white clover) are still limited to the lawns around a few of the buildings such as the Marine Barracks and the Enlisted Naval Personnel Barracks. Others such as *Taraxacum officinale* (common dandelion) are common in rocky and sandy soil around buildings and along roadsides and parking-lot edges.

The distribution of *Poa trivialis* has already been given in the hillside slope section. Hultén (1968) separates *Poa leptocoma* (bog bluegrass), *P. paucispicula*, and *P. merrilliana* into three different species. In the discussion of *P. leptocoma*, Hultén (1973) believes the existence of *P. leptocoma* to be doubtful and believes it may be wisest to exclude *P. leptocoma* Trin. from the Alaskan flora since the specimens are actually *P. paucispicula*. But Welsh (1974) groups these three species in *P. leptocoma* Trin. This is the first time that *P. leptocoma* has been reported from the Aleutians, even if the range distribution of the three species is grouped together. Because it was collected from around the buildings on Bering Hill of the Naval Station, it probably has been introduced on Adak Island.

Figure 13. Rock outcropping.

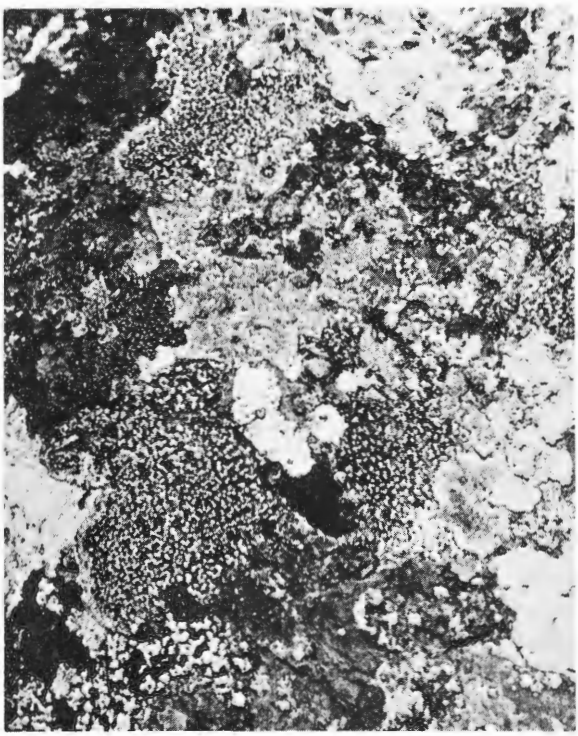

Figure 14. Lichens and mosses on rock outcroppings.

Figure 15. Peak of Mount Moffett (elev. 1.74 km).

Figure 16. *Heracleum lanatum* along roadside.

Prunella vulgaris var. *lanceolata* is found over much of central and southern North America. But in Alaska it is only known from the southeastern coast, several locations in interior Alaska, and scattered through the Aleutians. It now appears more continuous in the Aleutians.

Of the other plants believed to have been introduced, all of them are outside their normal ranges according to Hultén (1968). *Alopecurus pratensis* (meadow foxtail) is found over most of North America, Asia, and Europe but only as far west in the Aleutian Islands as Unalaska Island. *Bellis perennis* is found over most of Europe and also in the northeastern and western United States and on Unalaska Island where it has probably been introduced also. *Cerastium vulgatum* is found across central North America, Asia, and Europe. It is also found in southern Alaska, as far west in the Aleutians as Umnak Island and on Amchitka and Attu islands. *Dactylis glomerata* (orchard grass) is found in central North America, in Europe, southeastern Alaska, Unalaska, St. George, and the Commander Islands.

Trifolium pratense is known from central North America, southern and southeastern Alaska, and in the Aleutians on Atka Island. It is also found in eastern and central Asia and most of Europe. *Trifolium repens* has approximately the same distribution but has been found in more locations in the Aleutians. It has recently been reported from Amchitka Island (Kazmaier, 1968; Shacklette et al., 1969; Hultén, 1973). Its distribution is now almost continuous through the Aleutians. Possibly it will not spread to other islands, as Kazmaier notes, since no seed was found on Amchitka Island.

CONCLUSION

I collected specimens from a total of 134 different species among 89 different genera and 39 families. A total of 46 species had not been reported from Adak Island, and 26 species are outside their known range according to the range distribution maps in Hultén (1968). For five species *(Calamagrostis lapponica, Eleocharis quinqueflora, Poa leptocoma, Potamogeton pectinatus,* and *Ranunculus occidentalis* var. *brevistylis)* this is the first-known collection in the Aleutian Islands.

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I would also like to thank Dr. John D. Dodd and especially Dr. Richard W. Pohl of Iowa State University for obtaining financial aid, working space, and access to the facilities of the Anderson herbarium during the time I spent identifying my specimens there. To several students at Iowa State, including Tom Lammers who guided me around the herbarium and located needed materials and Karen Kuenzel who helped put together the maps of Adak Island and determine elevations, I wish to express my gratitude and thanks.

Finally, I wish to express my thanks to Dr. John D. Koppen of Rutgers University, Newark, New Jersey, and to Bonnie Fraser for their assistance in the preparation of this manuscript.

APPENDIX

SPECIES LIST BY FAMILIES

PTERIDOPHYTA

LYCOPSIDA

Isoetaceae (Quillwort Family)

W *Isoetes echinospora* Dur. (Quillwort)—1

Lycopodiaceae (Clubmoss Family)

A *Lycopodium alpinum* L. (Alpine Clubmoss; Ground Fir)—6

W *L. annotinum* L. var. *annotinum* (Stiff Clubmoss)—6

W *L. clavatum* L. (Running Clubmoss)—5, 6

A *L. selago* L. (Fir Clubmoss)—5, 6

A *L. selago* L. var. *selago*—5, 6

SPHENOPSIDA

Equisetaceae (Horsetail Family)

A *Equisetum arvense* L. (Meadow Horsetail)—5, 11, 12

PTEROPSIDA

Polypodiaceae (Common Fern Family)

A *Athyrium filix-femina* (L.) Roth (Lady Fern)—4

A *Gymnocarpium dryopteris* (L.) Newman (Oak-fern)—4

A *Thelypteris limbosperma* (All.) H. P. Fuchs (Mountain Wood-fern)—4

A *T. phegopteris* (L.) Slosson in Rydb. (Northern Beech-fern)—4

SPERMATOPHYTA

PTEROPSIDA

GYMNOSPERMAE

Pinaceae (Pine Family)

I O *Picea sitchensis* (Bong.) Carr. (Sitka Spruce)—13

DICOTYLEDONAE

Campanulaceae (Bellflower Family)

A *Campanula chamissonis* Federov (Hairy-flowered Harebell)—8

A *C. lasiocarpa* Cham. (Mountain Harebell)—8

Caprifoliaceae (Honeysuckle Family)

A *Linnaea borealis* L. var. *borealis* (Twin-flower)—6

Caryophyllaceae (Pink Family)

O *Arenaria lateriflora* L. (Blunt-leaved Sandwort)—6

A *A. peploides* L. var. *major* Hook. (Sea-beach Sandwort)—12

A *Cerastium fischerianum* Ser. ex DC. (Fischer Chickweed)—4

I O *C. vulgatum* L.—10

I O *Sagina saginoides* (L.) Britt. (Arctic Pearlwort)—3

A *Stellaria calycantha* (Ledeb.) Bong. var. *bongardiana* (Fern.) Fern.—5, 10

Compositae (Composite Family)

A *Achillea millefolium* L. ssp. *borealis* (Bong.) Breitung (Yarrow)—10, 11, 12

A *Anaphalis margaritacea* (L.) B. & H. (Pearly Everlasting)—7, 11

A *Antennaria dioica* (L.) Gaertn.—7

A *Arnica unalaschcensis* Less.—6

I O *Bellis perennis* L. (European Daisy)—3
A *Erigeron peregrinus* (Pursh) Greene ssp. *peregrinus*—6
A *Hieracium triste* Willd. (Wooly Hawkweed)—6
A *Petasites frigidus* (L.) Fries (Arctic Sweet Coltsfoot)—3, 5
A *P. frigidus* (L.) Fries var. *frigidus*—5
A *P. frigidus* (L.) Fries var. *nivalis* (Greene) Cronq.—4
A *Senecio pseudo-arnica* Less.—12
I O *Taraxacum officinale* Weber ex Wiggers (Common Dandelion)—9, 10

Cornaceae (Dogwood Family)

A *Cornus suecica* L. (Swedish Cornel)—5, 6

Cruciferae (Mustard Family)

W *Barbarea orthoceras* Ledeb. (Wintercress)—9, 12
A *Cardamine oligosperma* Nutt. ex T. & G. var. *kamtschatica* (Reg.) Detl.—5

Empetraceae (Crowberry Family)

A *Empetrum nigrum* L. (Crowberry)—5, 6, 7
O *E. nigrum* L. ssp. *hermaphroditum* (Lge.) Sor.—6

Ericaceae (Heath Family)

A *Loiseleuria procumbens* (L.) Desv. (Alpine Azalea)—5, 6
W *Rhododendron camtschaticum* Pallas ssp. *camtschaticum* (Kamchatka Rhododendron)—4

Geraniacae (Geranium Family)

A *Geranium erianthum* DC. (Northern Geranium)—6

Haloragaceae (Watermilfoil Family)

W *Hippuris vulgaris* L. (Common Marestail)—1
W *Myriophyllum spicatum* L. (Spike Watermilfoil)—1
W *M. spicatum* L. var. *exalbescens* (Fern.) Jeps—1

Labiatae (Mint Family)

O *Prunella vulgaris* L. var. *lanceolata* (Barton) Fern. (Heal-all)—3

Leguminosae (Pea Family)

W *Lathyrus japonicus* Willd. var. *japonicus* (Beach-pea)—10, 12
A *Lupinus nootkatensis* Donn ex Sims var. *nootkatensis* (Nootka Lupine)—6
I O *Trifolium pratense* L. (Red Clover)—10
I O *T. repens* L. (White clover)—3

Lentibulariaceae (Bladderwort Family)

A *Pinguicula vulgaris* L. var. *Macroceras* (Link) Herder (Bogviolet)—5

Onagraceae (Evening-Primrose Family)

A *Epilobium alpinum* L. var. *behringianum* (Hausskn.) Welsh (Alpine Willow-herb)—5, 12
W *E. angustifolium* L. var. *abbreviatum* (Lunell) Munz (Fireweed)—10
W *E. angustifolium* L. var. *angustifolium*—4, 10

Plantaginaceae (Plantain Family)

A *Plantago macrocarpa* Cham. and Schlecht. (Seashore Plantain)—5, 6

Polygonaceae (Buckwheat Family)

A *Polygonum viviparum* L. (Alpine Bistort))6
I O *Rumex acetosella* L. (Sheep Sorrel)—12

Portulacaceae (Purslane Family)

A *Montia sibirica* (L.) Howell (Siberian Spring-beauty)—4

Primulaceae (Primrose Family)

A *Primula cuneifolia* Ledeb. var. *saxifragifolia* (Lehm.) Pax ex Engler (Wedge-leaf Primrose)—5

A *Trientalis europaea* L. (Arctic Starflower)—6

Ranunculaceae (Buttercup Family)

A *Aconitum maximum* Pallas ex DC. (Kamchatka Aconite; Monkshood)—4, 5, 6

A *Anemone narcissiflora* L. var. *villosissima* DC.—5, 6

A *Caltha palustris* L. var. *asarifolia* (DC.) Huth. (Yellow Marsh-marigold)—2

A *Coptis trifolia* (L.) Salisb. (Trifoliate Goldthread)—5

A *Ranunculus aquatilis* L. (Water Crowfoot)—1

A *R. aquatilis* L. var. *capillaceus* (Thuill) DC.—1

A *R. flammula* L. var. *ovalis* (Bigel) Benson (Creeping Spearwort)—1

O *R. occidentalis* Nutt. ex T. & G. var. *brevistylis* Greene (Western Buttercup)—5

A *R. occidentalis* Nutt. ex T. & G. var. *nelsonii* (DC.) Benson—5, 6, 9

Rosaceae (Rose Family)

A *Geum calthifolium* Menzies ex Rees (Caltha-leaf Avens)—5

A *G. pentapetalum* (L.) Makino (Low Avens)—5

A *Rubus stellatus* J. E. Smith (Nagoon Berry)—5, 6

Rubiaceae (Madder Family)

A *Galium trifidum* L. var. *pacificum* Wieg. (Small Bedstraw)—4

Salicaceae (Willow Family)

A *Salix arctica* Pallas (Arctic Willow)—6, 8

I O *S. barclayi* Anderss. (Barclay Willow)—13

O *S. polaris* Wahl. (Polar Willow)—6

Saxifragaceae (Saxifrage Family)

A *Leptarrhena pyrolifolia* (D. Don) R. Br. ex DC. (Leatherleaf Saxifrage)—5

A *Parnassia kotzebuei* Cham. ex Spreng. (Kotzebue Grass-of-Parnassus)—5

Scrophulariaceae (Figwort Family)

A *Euphrasia arctica* Lange ex Rostrup var. *mollis* (Ledeb.) Welsh (Arctic Eyebright)—5

O *Limosella aquatica* L. (Mudwort)—1

A *Mimulus guttatus* DC. (Yellow Monkey-flower)—4

A *Pedicularis chamissonis* Steven (Chamisso Lousewort)—5, 6

A *Rhinanthus crista-galli* L. (Rattlebox)—10

A *Veronica americana* Schwein. ex DC. (Speedwell)—4

A *V. serpyllifolia* L. var. *humifusa* (Dickson) Vahl (Thyme-leaf Speedwell)—5

A *V. wormskjoldii* Roem. and Schult. var. *stelleri* (Pallas) Welsh (Alpine Speedwell)—6, 7

Umbelliferae (Carrot Family)

A *Conioselinum chinense* (L.) B.S.P. (Western Hemlock-parsley)—4, 5, 6

W *Heracleum lanatum* Michx. (Cow Parsnip)—4

Violaceae (Violet Family)

A *Viola langsdorffii* (Reg.) Fisch. ex DC. (Alaska Violet)—4, 5, 6, 8

MONOCOTYLEDONAE

Cyperaceae (Sedge Family)

A *Carex anthoxanthea*—5
O *C. aquatilis* Wahl. (Water Sedge)—2
W *C. lyngbyei* Hornem. (Lyngbye Sedge)—3, 5
A *C. macrochaeta* C. S. Mey. (Long-awn Sedge)—3, 5
A *C. pluriflora* Hultén (Many-flower Sedge)—5
O *Eleocharis quinqueflora* (Hartm.) Schwarz—5
O *Eriophorum angustifolium* Honck. (Tall Cottongrass)—2, 5
A *E. scheuchzeri* Hoppe (White Cottongrass)—5

Gramineae (Grass Family)

W *Agrostis alaskana* Hultén (Alaska Bentgrass)—5
I O *Alopecurus pratensis* L. (Meadow Foxtail)—3
A *Bromus sitchensis* Trin. var. *aleutensis* (Trin.) Hultén (Alaska Brome)—6
W *Calamagrostis canadensis* (Michx.) Beauv. var. *langsdorffii* (Link) Inman (Bluejoint)—6
O *C. lapponica* (Wahl.) Hartm. (Lapland Reedgrass)—6
W *C. nutkaensis* (Presl) Steud. (Pacific Reedgrass)—6
I O *Dactylis glomerata* L. (Orchard Grass)—3
A *Deschampsia beringensis* Hultén (Bering Hairgrass)—3, 6
Elymus X *aleuticus* (Hultén) Bowden—6
A *E. mollis* Trin. (Dunegrass)—6, 12
W *Festuca rubra* L. (Red Fescue)—5, 6
A *F. rubra* L. ssp. *aucta* (Krecz. and Bobr.) Hult.—6
A *Phleum alpinum* L. (Alpine Timothy)—6
W *Poa arctica* R. Br. (Arctic Bluegrass)—6
I O *P. leptocoma* Trin. (Bog Bluegrass)—3
I O *P. trivialis* L. (Rough Bluegrass)—3, 6
A *Trisetum spicatum* (L.) Richter (Downy Oatgrass)—6

Iridaceae (Iris Family)

W *Iris setosa* Pallas var. *setosa* (Wild Iris, Flag)—5, 6

Juncaceae (Rush Family)

A *Juncus arcticus* Willd. var. *balticus* (Willd.) Trautv. (Arctic Rush)—5
A *J. ensifolius* Wikstr.—5
O *J. falcatus* E. Meyer var. *sitchensis* Buch. in Engler.—4
A *J. mertensianus* Bong. (Mertens Rush)—5
W *Luzula campestris* (L.) DC. ex DC. and Lam. var. *minor* (Satake) Welsh—5
W *L. campestris* (L.) DC. ex DC. and Lam. var. *multiflora* (Ehrh.) Celak—5
A *L. parviflora* (Ehrh.) Desv. (Small-flowered Woodrush)—5

Liliaceae (Lily Family)

A *Fritillaria camtchatcensis* (L.) Ker (Indian-rice, Black Lily)—6
W *Streptopus amplexifolius* (L.) DC. (Cucumber-root, Clasping Twisted-stalk)—4
W *Tofieldia coccinea* Richards. (Northern Asphodel)—6

Orchidaceae (Orchid Family)

A *Habenaria behringiana* (Rydb.) Ames (Bering Bog-orchid)—5

A *H. dilatata* (Pursh) Hook. (White Bog-orchid)—5

A *H. hyperborea* (L.) R. Br. ex Ait. var. *viridiflora* (Cham.) Welsh (Northern Bog-orchid)—5

O *Listera convallarioides* (Sw.) Nutt. (Broad-leaved Twayblade)—4

A *L. cordata* (L.) R. Br. ex Ait. (Heart-leaved Twayblade)—5

A *Orchis aristata* Fisch. ex Lindl. (Fischer's Orchis)—5, 8

Potamogetonaceae (Pondweed Family)

O *Potamogeton pectinatus* L. (Fennel-leaf Pondweed)—1

A *P. praelongus* Wulf. (White-stemmed Pondweed)—1

Sparganiaceae (Burreed Family)

A *Sparganium hyperboreum* Laest. (Northern Burreed)—1

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PERCEPTION OF WATER POLLUTION IN A RURAL AREA: A COGNITIVE DISSONANCE APPROACH

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ABSTRACT. A study concerning perception of water pollution was conducted among the inhabitants of a rural agricultural area. The study attempted to identify significant factors that affect perception of water pollution.

After presentation of the application of cognitive dissonance theory to the analysis of the problem, three hypotheses were generated: (1) Farmers are less likely than nonfarmers to perceive agricultural practices as major sources of pollution. (2) No direct relation exists between knowledge of polluted areas and perception of agricultural practices as major sources of pollution. (3) Personal experience with polluted water is directly related to perception of water pollution as a major problem. The first two hypotheses were confirmed; the third was rejected. Possible reasons for discrepancies in theory and data and implications for policy programs are briefly discussed.

INTRODUCTION

Recently, one element of the population has been expressing a growing concern about environmental quality and the deteriorating ecological balance. This group, composed of concerned citizens as well as ecological specialists, has sparked legislation that is hoped to be an initial attempt to save the environment and keep the world habitable for all forms of life, including humans.

Several factors related to the growing concern for our deteriorating environment are: (1) increasing population pressures; (2) the increase in per-capita consumption of resources; and (3) the increasing pace of technological development, which has brought with it an accelerating amount of pollutants to our total environment. Water pollution is no small part of this problem. Considering these factors and the present rate of water consumption, a water shortage of 100 billion gallons a day for the U.S. in 1980 has been predicted by Rienow and Rienow (1967, p. 79).

Rural areas have their problems when we consider the quality of the environment. Feedlot runoff; pesticide, herbicide, and fertilizer residues; and soil erosion are increasing problems that must be faced as farmers attempt to increase production. Sanitary systems in small rural communities are insufficient or even lacking in many instances.

The social response of citizens has become almost overwhelming, yet the issues seem to persist. The following questions have arisen: To what extent is the general public aware of the severity of the crisis? What factors are important in determining individual perceptions of pollution? How do individuals perceive agricultural practices in relation to the pollution problem? What factors can distort or enhance these perceptions? The application of cognitive dissonance theory to the analysis of the problem is the focus of this discussion.

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COGNITIVE DISSONANCE THEORY

Research indicates that, if a hazard (pollution) directly influences the user, perception of the hazard is strengthened (Burton, 1962; Kates, 1962; Burton and Kates, 1964b; Saarinen, 1966; Kates, 1967). But why, when no alternatives are available, does the user distort or even eliminate the perception of a hazard that affects him directly (Burton, 1962; Barker, 1968)? Cognitive dissonance theory can help explain this phenomenon.

Although this theory is not the only way to view perceptions of hazards, it is a means of analyzing a problem from a particular perspective,which, it is hoped, will bring understanding to various alternatives of perception of the problem. Although cognitive dissonance theory has been criticized as an *ad hoc* explanation of phenomena that can be adjusted to verify any results (Kiesler et al., 1969, p. 236), insights into the problem of perception can be obtained by its use.

According to Festinger (1957, p. 1-3), an individual strives toward internal personal consistency. The person's opinions and attitudes, for example, tend to exist in internally consistent clusters. Dissonance is the existence of nonfitting relations among cognitions (any knowledge, opinion, or belief about the environment, about oneself, or about one's behavior). The existence of this inconsistency (cognitive dissonance), being psychologically uncomfortable, will motivate the person to try to reduce the dissonance and achieve consonance.

Dissonance can be reduced in three ways (Festinger, 1957, p. 18-24): (1) by changing one's behavior, (2) by changing the environment, and (3) by adding new cognitive inputs. For some circumstances, however, dissonance will be tolerated rather than reduced. Festinger (1957, p. 24-26) delineates three conditions under which this can occur: (1) dissonance reduction may be painful or costly; (2) dissonance may be accompanied by other conditions that are highly satisfying; (3) dissonance reduction may be impossible because of existing circumstances.

If perception is viewed as the way an individual responds to any sense or impression detected (Rogers, 1962, p. 303), then cognitive dissonance theory can explain the manner by which the antecedent stimuli are transformed into the resultant perception. For example, even though a recreation area is obviously polluted, a person may not perceive it to be polluted despite the fact that it may be a direct hazard to his health. How did this happen? At first, dissonance was created. An inconsistency existed between the person's desire for health and security and the knowledge that the effects of pollution might make that impossible. The person did not wish to change his behavior to reduce the inconsistency, either because the swimming act, the surroundings, andfriendships at the location were very satisfying or because another alternative might be painful or costly, such as being forced to travel farther, to pay more, or even to give up the activity and enjoyment of swimming. Therefore, if dissonance were to be reduced, a new cognitive input had to be added. Either the source of the information was discredited, or the potential threat was re-evaluated by obtaining additional information more congruent with one's cognition.[4]

HYPOTHESES

Three major hypotheses guide the design of this study.

Hypothesis 1. *Farmers are less likely than nonfarmers to perceive agricultural practices as major sources of pollution.*

Although there is evidence (Burton, 1962; Burton and Kates, 1964a) that farmers have a keener awareness of natural hazards than persons in other occupational categories, research has suggested that this awareness is due to three causal variations in perception as explained by Burton and Kates' three hypotheses (1964b). In reviewing and summarizing their previous

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[4] Examples of hazard research using cognitive dissonance theory deal with perception of the contribution smoking makes to the health of its user. Festinger (1957) and Pervin and Yatko (1965) found, when smokers and nonsmokers had equal knowledge concerning the potential threat of what smoking can cause, that heavy smokers were the most skeptical of the health hazard. They tended to discount the validity of research findings, and to minimize the the perception of danger to themselves more than did nonsmokers.

research, they found that the degree to which the hazard is directly related to the user, the frequency of the hazard, and the user's degree of personal experience with the hazard can all affect the user's perception of risk.

Agricultural pollution is a major problem in Iowa. With little industry and no large metropolitan areas, the predominant pollutants are soil, pesticides, herbicides, and fertilizers washed from the land to create an imbalance in aquatic, as well as human, ecological systems. These effects, however, in most instances are not directly apparent at their point of origin. Applications of chemicals have great advantages for the farmer, resulting in higher yield and greater efficiency with less effort expended. Although the farmer frequently has personal experience with the polluting agents and is directly related to them in his farm operation, the negative effects of these pollutants may not have direct adverse effects upon him or his operation. It is more likely that nonfarmers, particularly urban dwellers, will suffer the consequences in their drinking water from chemicals and decaying aquatic corpses brought downstream, in their rivers and reservoirs in dredging operations from silting, and in their taxes to correct for this pollution. Farmers, on the other hand, usually have underground water sources that are less susceptible to the surface contaminants.

Beyond this, however, there is another reason for differential perception between farmers and nonfarmers. According to cognitive dissonance theory, one would expect farmers to be less perceptive of the problem than nonfarmers. Individuals would experience dissonance between certain beliefs—the addition of certain chemicals improves crop yields with greater efficiency, for greater marketable quality, for profit maximization—and the newer acquired information that these same practices have detrimental latent effects. A nonfarmer might quite easily change his belief to agree with the new finding. However, if the farmer changes his belief to achieve consonance, he must note his use of those farming practices. Elimination of those practices could be perceived to be quite costly, both economically in loss of yield and profit, and physically in the need for alternative weed-control methods. Given this perspective, the farmer likely would attempt to add new cognitive inputs through additional information that invalidates or redefines the problem, rather than to change his behavior. As Festinger (1964, p. 1) stated, "If one obtains an accurate measurement of the net attractiveness of each of the alternatives, one can predict with reasonable accuracy that the person will choose that alternative which is most attractive."

Hypothesis 2. *No direct relation exists between knowledge of polluted areas and perception of agricultural practices as major sources of pollution.*

Previous research (Roder, 1961; Burton, 1961; Kates, 1962; Kates, 1963; Pervin and Yatko, 1965; Saarinen, 1966) indicated that knowledge is not a meaningful variable in determining accurate perception of a hazard. If viewed from the perspective of cognitive dissonance theory, acquired knowledge of a polluted area may be considered a dissonance-producing factor. For the farmer, if the source of pollution is considered to be agricultural practices, his most likely alternative would be to discount the validity of the source and, quite possibly, place the source of the pollution elsewhere as with industry or cities (Barker, n.d.). If the source of pollution is considered to be elsewhere, the farmer should have very little dissonance problem, and his cognitive adjustment would be in agreement with his own belief system. For the nonfarmer, if the polluted area does not directly affect him, the issue may be nonsalient, having little, if any, effect on his cognitions.

Hypothesis 3. *Personal experience with polluted water is directly related to perception of water pollution as a major problem.*

As indicated by previous research (Roder, 1961; Burton, 1961; Burton, 1962; Kates, 1962; Kates, 1963; Burton and Kates, 1964b; Saarinen, 1966; Kates, 1967), personal experience with a hazard is related to more accurate perception of that hazard. The dissonance created by personal contact with water believed to be polluted would create a greater problem than when the source of dissonance was simply knowledge. It is difficult to discredit the source of the dissonance problem when the source is one's own perceptions. The alternative then would be to consider changing one's belief that water pollution is a salient problem. The degree to which this belief would change depends on the frequency and degree of the experience.

METHODS

Six predominantly rural Iowa counties were selected as a universe. A stratified area sample was selected, with emphasis placed on the rural segment of the population (the largest town included had 8,000 inhabitants). A total of 137 adult (45.3% males and 54.7% females) respondents completed the interview. The median age of the sample was 49 years, ranging from 20 to 82 years of age. Almost three-tenths (29.2%) of the sample had less than a high school education, and about half (51.8%) completed high school, with another two-tenths (19.0%) completing some education beyond high school. Fifty-five (40.1%) of the respondents had a farm residence; forty-six (33.6%) were rural nonfarm (open country-town of 2,500); and only thirty-six (26.3%) lived in a town of 2,500 or more.

To activate the concepts in the hypotheses, the following variables were used. Residence was used to determine the orientation of the respondents, rather than the occupation. A dichotomous variable, farm—nonfarm, was used in which the latter category included rural nonfarm, as well as urban residences.

Knowledge, also a dichotomous variable, was determined by a positive or negative response to the question: "Some people have been concerned with pollution of rivers, streams, and lakes in Iowa. Do you have personal knowledge of any polluted recreational facilities in the state?" This item attempts to evaluate respondent awareness of specific problem areas, not abstract possibilities.

Personal experience was also a subjective evaluation by the respondent. Responding to the dichotomous question: "Have you had any personal experience with water that you considered to be polluted?", the interviewee is using his own definition of water pollution rather than a definition imposed upon him. Thus, no matter what the actual condition of water is, the interpretation is the subjective evaluation of the respondent.

To measure the extent to which the respondent perceived that present agricultural practices are contributing to the pollution problem, the item, "Agricultural practices are major sources of water pollutants in Iowa," was used. "Pollution of water is not a major problem in Iowa," was used as the indicator of respondent perception of the degree of the problem statewide.

The two items, (1) agricultural practices as major sources of water pollutants and (2) water pollution as a major problem, were scored by using the certainty method (Warren et al., 1969). This unequal interval, 11-alternative, 16-point range scale places greater weight on extreme decisions and has been demonstrated to give greater differentiation among responses than Likert scoring techniques.

A one-way classification analysis of variance (Steel and Torrie, 1960, p. 218) was used to measure the relationship between the dichotomous variables and the interval variables. A correlation was run between the two interval variables. It was assumed that items scored by using the certainty method were interval variables and, because of the number of alternatives, continuous in nature. Thus, parametric statistical techniques were appropriate for analysis.

RESULTS

Source of Pollution Problem

When analyzing the relationship between residence category and attitude toward agricultural practices as a major pollutant, a significant difference was found between the mean response of farm and nonfarm residents ($F = 17.81, \alpha = .05, n = 137$). The actual means obtained were 5.55 for farm residents and 8.98 for nonfarm residents, with 16 indicating strong agreement, 8 indicating neutrality, and 0 indicating strong disagreement with the item. An intercorrelation coefficient of 0.34 was obtained in relating the two variables. These results lend supporting evidence to the first hypothesis that farmers are less likely than nonfarmers to perceive agricultural practices as major sources of pollution.

When testing for a difference between those with personal knowledge and those without such knowledge in relation to the item concerning agricultural practices, no significant difference was found ($F = 2.69, \alpha = .05, n = 137$). When testing separately for farm residents and nonfarm residents, no significant differences were found between the knowledge and no-knowledge groups for either residence category (See Table 1). When relating the two variables, intercorrelation coefficients of 0.139, 0.049, and 0.156 were obtained for the total sample,

Table 1. Relationships among source of pollution perception variables (F values)

	Agricultural Practices Are Major Sources of Water Pollutants in Iowa		
	Farm n = 55	Nonfarm n = 82	Total Sample n = 137
Farm—Nonfarm			17.81*
Knowledge—No Knowledge	0.13	2.27	2.69
Experience—No Experience	1.53	0.03	0.44

*Significant at the .01 level

farm residents alone, and nonfarm residents alone, respectively. Thus, evidence is obtained in support of the second hypothesis that no direct relation exists between knowledge of polluted areas and perception of agricultural practices as major sources of pollution.

Those with personal experience and those without show no significant differences when measured on the item of agricultural practice. When analyzed separately for farmers and nonfarmers, no significant differences between experience and no-experience groups were obtained for either farm residents or nonfarm residents. (See Table 1).

Degree of Pollution Problem

Farm residents and nonfarm residents were analyzed in relation to the item concerning pollution as a major problem, and statistically significant differences between the two groups were obtained ($F = 4.32$, $\alpha = .05$, $n = 137$). The actual means obtained were 9.727 for farm residents and 11.232 for nonfarm residents, with 0 indicating strong agreement, 8 indicating neutrality, and 16 indicating strong disagreement with the item.

Table 2. Relationships among degree of pollution perception variables (F values)

	Pollution of Water is Not a Major Problem in Iowa		
	Farm n = 55	Nonfarm n = 82	Total Sample n = 137
Farm—Nonfarm			4.32*
Knowledge—No Knowledge	2.14	2.43	5.76*
Experience—No Experience	2.00	0.11	0.30

*Significant at the .05 level

A statistically significant difference was found between knowledge and no-knowledge groups when measured by using the item concerning pollution as a major problem. As in the previous test, however, the results are not significant at the .01 level. Also, when residence groups are tested separately, no significant differences exist between knowledge and no-knowledge groups among farm residents and nonfarm residents (See Table 2).

When personal experience was tested with the item concerning pollution as a major problem, no significant difference was found between those who had had personal experience with water they considered polluted and those who had no such experience ($F = .30$, $\alpha = .05$, $n = 137$). When the same test was conducted, controling for residence, no significant differences were discovered between either residence category (See Table 2). When relating the two variables, intercorrelation coefficients of 0.047, 0.191, and 0.037 were obtained for the total sample, farm residents alone, and nonfarm residents alone, respectively. This evidence

does not lend support to the third hypothesis that personal experience with polluted water is directly related to perception of water pollution as a major problem.

A correlation was made between the item concerning agricultural practices as pollutants and the item concerning pollution as a major problem. A value of 0.210 was obtained, significant at the .05 level (n = 137).

DISCUSSION

Statistically, the first two hypotheses were supported and the third was rejected. The only difference between groups that could be considered substantive was between farm residents and nonfarm residents when measured on their perception of agricultural practices as major sources of water pollutants. When the same two groups were measured on their perception of water pollution as a major problem, however, the differences between groups were barely significant (Table 1). This might imply that both farmers and nonfarmers are approximately equally aware of water pollution as a problem but that farmers, as compared with nonfarmers, have a different perception of the source of the problem. Even so, nonfarmers show, by their mean score, only a slight indication that they believe agricultural practices are the source of the problem. This may imply that the problem of increasing perceptual awareness of the source of pollution does not lie with the farmers alone.

As hypothesized, knowledge of polluted areas was not a meaningful variable in measuring perception of agricultural practices as sources of water pollutants. Even when farmers and nonfarmers were analyzed separately, differences in knowledge had no significant effect on perception. Although barely statistically significant, differences in knowledge of polluted areas could not be considered substantively significant when measured by the perception of pollution as a major problem. When analyzed separately according to farmers and nonfarmers, this slight relationship for the total sample disappeared. The relationship may have been due to an interaction effect with the farm—nonfarm dichotomy. The implication of these findings seems that educational programs by themselves may not be the answer to achieving changes in perceptual awareness concerning the environment.

For education to be effective, a dissonance-producing situation must be created in which the behavioral alternative is viewed by the individual to be advantageous. For example, a means of changing farm practices that contribute to water pollution may be to demonstrate to the individual that it is to his own advantage to adopt or terminate certain practices rather than appealing to general altruistic motives.

Contrary to the hypothesis, personal experience was found to have virtually no relationship with perception of water pollution as a major problem. This also was true when farmers and nonfarmers were analyzed separately. When personal experience was measured by the perception of agricultural practices as sources of water pollutants for the total samples, farmers alone, and nonfarmers alone, the results again were the same. This discrepancy of the hypothesis with previous findings might be accounted for by considering in what manner individuals perceived the phenomena they experienced. In previous research (Kates, 1962; Kates, 1963) the expectation of the degree of a future threat was found to be related to the interpretation of that threat. In other words, if the threat was interpreted as continuous and increasing in intensity, a greater perception of threat would result than if the threat was viewed as being unique. To apply this to the population: if the individual feels that his experience with polluted water was an isolated or unique event, it is not likely that he will perceive water pollution as being a major problem statewide. Further investigation should be considered of personal interpretation of the phenomenon experienced with polluted water to determine what effect it has on perception of the total environmental problem. If findings indicate that erroneous interpretation of personal experience is a significant factor in determining perception of the pollution problem, it might imply that changing perceptual awareness may be difficult even when the pollution has reached the degree of being directly related to the user.

Concerning the knowledge of respondents in relation to polluted recreational facilities within the state, the distribution of responses according to residence seems to indicate, based on percentages obtained, that the number of urban residents who are knowledgeable is greater than the number of rural residents within this sample (See Table 3). For the entire sample, however, less than one-fourth of the respondents had any knowledge of pollution in recreational areas. This may indicate either a lack of educational information concerning the problem that reaches the individual, or a lack of salience of the issue of water pollution for the individual. In the latter instances the individual may selectively ignore pollution information.

Table 3. Knowledge of polluted recreational facilities

	Farm		Rural—NonFarm		Urban		Total	
	No.	%	No.	%	No.	%	No.	%
Knowledge	8	14.5	9	19.6	14	38.9	31	22.6
No Knowledge	47	85.5	37	80.4	22	61.1	106	77.4
	55	40.1	46	33.6	36	26.3	137	100.0

$\chi^2 = 7.73$ Significant at .05 level

In considering those who had personal experience with what they believed to be polluted water, once again the percentage of urban respondents who had experience is slightly higher than for rural respondents (See Table 4). Also, those with experience constitute only one-fourth of the sample. It could be that the low percentages obtained are due to the fact that

Table 4. Personal experience with polluted water

	Farm		Rural—NonFarm		Urban		Total	
	No.	%	No.	%	No.	%	No.	%
Personal Experience	13	23.6	10	21.7	11	30.6	34	24.8
No Personal Experience	42	76.4	36	78.3	25	69.4	103	75.2
	55	40.1	46	33.6	36	26.3	137	100.0

$\chi^2 = .911$ Not Significant

either the types of pollution present are not directly recognizable or that the individual does not know what constitutes pollution and therefore does not know what to look for in pollution. It also is possible that the issue is not salient because no personal threat or detriment has been experienced by the individual. According to data in Table 5, only 6.6% of the total sample had any experience with polluted water that had been detrimental to their health.

Table 5. Personal experience with polluted water detrimental to health

	Farm		Rural—NonFarm		Urban		Total	
	No.	%	No.	%	No.	%	No.	%
Experience Detrimental	4	7.3	3	6.5	2	5.6	9	6.6
Experience not Detrimental	9	16.4	7	15.2	9	25.0	25	18.2
No Personal Experience	42	76.4	36	78.3	25	69.4	103	75.2
	55	40.1	46	33.6	36	26.3	137	100.0

$\chi^2 = 1.55$ Not Significant

Because of the low percentage of persons who had unpleasant experiences with water pollution, it may be that few believe the situation is one of concern or that it even exists. Thus, we can conclude that, according to the magnitude of responses to our questions on pollution, respondents have little awareness of a pollution problem. Therefore, agricultural pollution is not a salient issue. Not only is the magnitude of the problem misperceived, but the source of the problem is not accurately perceived by those who believe a problem exists.

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SPECIAL GOVERNMENTAL DISTRICTS IN THE 1970'S: CHANGING IMPORTANCE OF SPECIAL DISTRICTS IN GOVERNMENTAL ORGANIZATION DURING THE LATE 1960'S AND EARLY 1970'S

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INTRODUCTION

Major changes in demographic and socioeconomic characteristics of the United States have not been followed by corresponding alterations in traditional forms of local government.[1] Rather, the service needs of rural, nonfarm dwellers and residents of exurbia are being met in a haphazard manner through proliferation of mistily conceived units called special districts, and through hodge-podge grants of additional ad hoc powers to existing counties.

The advantages of special districts are many. First is the relative ease by which special districts may be formed to meet problems confronting a community. Second, any tax and debt limitations applicable to cities and counties do not usually apply to special districts. Third, the creation of a new district superimposed upon an existing governmental structure seldom threatens the status or tenure of established political leadership in the community. Finally, special interest groups such as land developers have found the special district a useful vehicle for supporting their operations, such as financing subdivision improvements.

A basic problem confronting the analysis of special districts is the absence of a satisfactory working definition, even though the United States Bureau of the Census and various scholars have attempted such a definition. Often, state legislators, citizens, and state agencies are either unaware of such definitions or frequently find them so contradictory that they cannot formulate a working definition for their own utilization. The result is that state agencies, federal agencies, and researchers cannot be certain of such basic facts as how many special districts exist within the state, or what their functions and duties are.[2]

PURPOSE

There is a distinct need to ascertain the value of the Bureau of Census data for policy-making in consideration of the problems associated with the relative importance of the special district within local governmental jurisdictions. Analysis of recent data on special districts is nonexistent. Thus, this research was begun for the purpose of obtaining some conclusions about the characteristics of special districts in the period 1967 to 1972. These years were chosen since they are the last two in which the Census of Governments reports have been conducted. The changes between each year's data provide clues to the increasing or decreasing importance of special districts, and more specifically on functional types of special districts.

Investigation is directed toward a comparison of trends in special district characteristics in Iowa, contrasted to trends within the North Central Region and the nation. One major limitation of the data is that within each state the Census of Governments reports break the data down by functional types of districts, but no data are presented in regard to characteristics of each functional type of district or of characteristics of special districts by county. Unfortunately, the only data presented at the county level are the total number of special districts within each county and whether or not they are part of an intercounty district.

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Since interactions at the local governmental level are of crucial importance, the value of the Census of Governments data suffers from lack of more detailed indicators. To approximate the probable interactions at the local levels, generalizations must be derived from a comparative analysis of state, regional, and national characteristics.

Data from the 1967 and 1972 Census of Governments reports provide answers to the following and other related questions: What are the types of special districts present in Iowa; does each functional type in Iowa have the same relative number of districts that it does in the North Central Region? What functional types of districts are increasing or decreasing in number; and are these types of districts the same at all three levels of government studied, i.e., the U.S., the North Central Region, and Iowa? What functional types of districts are increasing or decreasing in their level of financial expenditures, revenues, and long- and short-term debt; are the changes in characteristics in the North Central Region and Iowa consistent with each other or do they reflect different trends in the region apart from the state? What are the characteristics unique to special districts within SMSA's? What interrelated or simultaneous changes in spatial characteristics of special districts accompany the changes in the number of special districts in Iowa as related to trends in the region and the nation?

DEFINITION OF SPECIAL DISTRICTS—CHARACTERISTICS NECESSARY FOR CLASSIFICATION AS A SPECIAL DISTRICT

Here a distinction must be made as to what constitutes a special district function according to the Bureau of the Census in contrast to the public's conception of special district functions when confused with similar functions of other local governmental agencies.[3] Special districts are limited-purpose governmental units that exist as separate corporate entities and have substantial fiscal and administrative independence from general-purpose local governments.[4] To the extent that they also provide many of the same services, special districts possess some of the same characteristics of general-purpose local governments, e.g., townships, counties[5] and municipalities. The performance of only a limited number of services, such as the specific special functions of fire protection, soil conservation, and drainage, differentiates special districts from other types of local government. These special-purpose governments are referred to as single or limited-purpose governments, special districts, public corporations, or public authorities.[6] Each special district is a separate governmental unit and must possess three attributes: existence as an organized entity, governmental character, and substantial autonomy.[7]

Existence as an organized entity

A district must have a name and must possess corporate powers such as perpetual succession, the right to sue and to be sued, and power to make contracts and to acquire and dispose of property. A number of these powers must be possessed but the absence of any one does not preclude classification as a special district.[8] Other units, which are organized entities but not specifically stated by law to be corporations, can also be special districts. To be counted as a special district government, all existing organized entities must be operating with a functioning board of trustees and possess some activities for carrying out the purposes of the entity.

Governmental character

The second prerequisite, governmental character, is demonstrated when officers of the entity are popularly elected or are appointed by public officials. A high degree of responsibility to the public, public reporting, and accessibility of records to public inspection also indicate governmental character. Attributes that do not preclude a class of units from being recognized as governmental in character if the entity meets the requirements as to public accountability and the election or appointment of officers are: the power to levy property tax, power to issue debt-paying interest exempt from federal taxation, and performance of a function regarded as governmental in nature.

Substantial autonomy

The third criterion is substantial autonomy. An entity meets this requirement when it has considerable fiscal and administrative independence.[9] Fiscal independence includes the power to prepare budgets, determine taxes, fix and collect charges, and to issue debt. Administrative independence is closely related to the selection of the entity's governing body, and is characterized by one of the following: a popularly elected governing body, a governing body representing two or more local or state governments, or performance of functions essentially different from those of, and not subject to specification of, the creating government.

According to the Bureau of the Census, noncritical definitional characteristics include geographic area, population, taxing power, and internal uniformity of taxation and services.

PROLIFERATION OF GOVERNMENTAL UNITS

The casual observer and more-informed citizen often are unaware of the changes occurring in the number of local governments, which are imputed to be accountable to the public. Some local governments are showing sizeable increases in their numbers. Data from 1967 and 1972 indicate that the number of special districts is increasing significantly in contrast to other local governments.[10] The number of school districts decreased sharply and counties showed little change in numbers, while only municipalities and special districts grew. For example, municipalities in Iowa increased by 6, a 0.6% increase between 1967 and 1972. Growth in municipalities is far outranked by growth in special districts in Iowa as well as in other states. Special districts in Iowa between 1967 and 1972 increased by 25, an increase of 11.6% from 280 districts in 1967 to 305 in 1972. When these percentages are extrapolated to determine the increase during a decade, the growth rate is approximately 23.3%.

The North Central Region of the U.S., in which Iowa is situated, has always had large numbers of special districts and large growth rates relative to those in the South, North East, and West.[11] The North Central Region had the greatest number of special districts during all the Census of Governments reporting periods from 1942 to 1972. Between 1967 and 1972, special districts in the North Central Region increased by 14.3% in contrast to a national increase of 12.3%. During the period the North Central Region's growth rate was double that of the North East and West. When these percentages are extrapolated to determine the increase during a decade, the growth rate is approximately 25%.

POTENTIAL PROBLEMS AND ACCOUNTABILITY WITH THE PROLIFERATION OF GOVERNMENTAL UNITS

Increases of this magnitude are significant even if no other data are examined. In contrast to more comprehensive allocations of powers and functions within a larger geographic or demographic area,[12] power formerly entrusted to counties and municipalities is increasingly becoming invested in a nebulous array of limited-purpose governments oriented to single-purpose functions.

Most of the changes in the number of special districts in the nation and the North Central Region between 1967 and 1972 were divided fairly equally between areas within and outside SMSA's (Standard Metropolitan Statistical Areas).[13] In Iowa the total amount of increase was absorbed outside of SMSA's, a change from 215 districts to 240. Districts within SMSA's numbered 65 in both 1967 and 1972.[14] This would indicate that Iowa's special district growth is atypical when contrasted to tendencies at the national and regional levels. Iowa's growth patterns represent a movement toward a proliferation of local governments in rural areas of the state, a contradiction of the continuing urbanization of the state's population. As urbanization draws population away from rural areas, fewer people are controlling more governmental functions, and especially so when additional governmental units are formed. Within certain county functions the power structure has potentially moved from county government toward control by special districts, thus enhancing the susceptibility of control by any one interest group.[15] When one considers that the net increase in special districts in Iowa occurred outside SMSA's, one wonders what is unique about Iowa's rural counties that requires use of the special district to provide certain limited-purpose functions for the county. Is something inherently wrong with the structure or responsiveness of county government, which in turn makes the special district attractive? Furthermore, is it beneficial for the

county to have certain powers delegated to limited-purpose governmental units (which often possess no debt limitations) rather than to accommodate various functional activities within the overall county planning and budgeting process? In any event the fact that many special district boundaries often are not coterminous with county boundaries suggests inability of existing county units to serve the population within certain areas of the county.[16] This would be in contrast to a uniform, countywide, service area. Certain functional activities have not been attractive to or accepted by the county as activities sufficiently important to be considered within the overall county budgeting and planning processes.[17] Rather, for some reason these activities have been entrusted to a group of individuals whose sole purpose is to pursue a limited set of objectives. This develops a strong tendency of catering to special interests, perhaps at the expense of the public. In addition, public accountability is obscured when governmental funds are spread among a multitude of limited-purpose governmental units.

STATISTICS AND SPECIAL DISTRICTS

The U.S. Department of Commerce's Bureau of the Census collects a wide variety of data for its Census of Governments reports. Data are collected for several jurisdictions: the nation, four U.S. regions, states, counties, municipalities, townships, school districts, and special districts. Beyond presentation of raw data, very little descriptive or analytic material is presented. Although the level of detail is adequate at the national, regional, and state levels, documentation of trends within counties and of functional types of special districts within counties is severely hampered by a general lack of detail. For example, functional types of special districts can be defined with respect to location and financial characteristics within regions or at state levels, but no data are available specifying where districts of each functional type are located throughout a state, or, more importantly, regarding what functional types of districts occur in each county. Nor are financial and spatial characteristics available for special districts on a county-by-county basis. Though data are subject to these limitations, the trends in special district growth patterns in the period between 1967 and 1972 can be grouped on the basis of functional, financial, and spatial characteristics as well as some characteristics of special districts as they relate to SMSA's.

EXAMINATION OF CHARACTERISTIC TRENDS OF SPECIAL DISTRICTS INDICATING MOST SIGNIFICANT INCREASES AND DECREASES BETWEEN 1967 AND 1972

Functional characteristics

Examination of changes in 20 types of single-function and 3 types of multiple-function special districts yields significant contrasts among the national, regional, and state data. Nationally the more traditional districts such as the drainage districts formed in the 1930's are losing their dominant position as the most frequent type of special district function. New demands for developing more socially oriented programs are linked to growth in special district numbers. Availability of more leisure time and changing lifestyles have increased the relative occurrence of parks and recreation districts, and the newly developing interest in federal subsidized housing from 1967 to 1972 has spurred the growth of housing districts.[18] In the nation between 1967 and 1972, the increases in the number of special districts by percentage of increase were housing and urban renewal districts by 45.1%, parks and recreation by 22.4%, hospital districts by 22.4%, health districts by 9.8%, water supply districts by 9.0%, library districts by 21.4%, and transit districts by 136.0%.[19] These changes are all indicators of urban problems and resultant methods of governmental responses.

Growths and declines in the North Central Region parallel those in the nation as a whole. Increases have occurred in health, fire protection, housing and urban renewal, and in "other" unclassified single-function districts. These functions increased in number by 101.0% for housing and urban renewal districts, 27.7% for parks and recreation districts, 112.2% for hospital districts, 60.6% for health districts, 31.7% for water supply districts, and 9.1% for transit districts. Overall, regional growth rates roughly coincided with national rates.

Iowa's special districts had a growth rate almost equal to the national rate. Beyond that the similarities end. Sewerage districts are still growing at a substantial rate in the U.S. and the North Central Region, but in Iowa are growing at five times those rates. The same is true of

fire-protection districts, which increased about five fold over the rates in both the region and the nation. Flood-control districts in Iowa between 1967 and 1972 increased at over twice the regional rate. Drainage districts did not increase in the nation or the region,[20] but increased by 10.8% in Iowa.

Highway districts decreased by 50.0% in Iowa, while no change occurred in the region, but in the U.S. the number increased by 9.8%.[21] Water-supply districts in Iowa decreased by 9.8%, while in the region the *increase* was three times the amount of Iowa's *decrease*;[22] in the nation as a whole the increase was 9.0%.

The number of special districts in Iowa increased by 25 (8.9%) between 1967 and 1972. Although the growth rate appears large, the actual number of special districts present in Iowa is small compared with the total number of local governments and the number of districts added between 1967 and 1972. Iowa's special-districts' growth patterns are unique when considered with regard to their actual numbers. Furthermore, Iowa's districts are definitely not the type of growth generators found at the regional and national levels and are more environmentally oriented. The trend in Iowa is toward provision of services to small communities and rural areas for such natural resource functions as flood control and drainage.

EXAMINATION OF SPATIAL CHANGES IN SPECIAL DISTRICTS

Relationship of city size to growth

Special districts in cities with a population of 25,000 or over showed an increase of over 33.0% between 1967 and 1972 in the U.S., the North Central Region, and Iowa.[23] There is some evidence of correlation between the larger cities (25,000 to 50,000) in Iowa and the increasing number of special districts between 1967 and 1972. For the nine communities listed in Iowa with a population over 25,000 but under 50,000 there was an overall increase of five special districts.[24] This is perhaps a response to service demands through formation of special districts in those communities. It is apparent in these five districts that the choice between community-provided services and the formation of special districts has been made, and that special districts have been a preference. Special districts within SMSA's and overlying a city of 25,000 or more increased by 37.1% in the U.S., by 35.8% in the North Central Region, but did not change in Iowa. Notably, districts outside SMSA's and overlying a city of 25,000 or more increased by 22.4% in the U.S., by 77.0% in the North Central Region, and by 100.0% in Iowa.[25]

Jurisdictional coincidence with other governmental units[26]

In the U.S. between 1967 and 1972, special districts coterminous with other governmental units increased by 14.9%. In the North Central Region the increase was 10.0%. Special districts in Iowa coterminous with other local governmental areas decreased by 7.4% in contrast to national and regional increases.

Citywide districts increased by 22.9% in the U.S., by 46.8% in the North Central Region, and by 44.5% in Iowa.

Coterminous districts[27]

Coterminous districts within SMSA's increased by 23.8% in the U.S., by 20.0% in the North Central Region, but decreased by 20.0% in Iowa. Between 1967 and 1972, coterminous districts increased outside SMSA's by 7.1% in the North Central Region, but decreased by 50.0% in Iowa.

Citywide districts increased by 20.0% in the U.S., by 55.0% in the North Central Region, but decreased by 50.0% in Iowa.

Noncoterminous districts[28]

Special districts noncoterminous with other local governments in the U.S. increased by 11.5% and within the North Central Region districts by 19.2%. Multicounty noncoterminous districts increased by 4.0% in the U.S., by 9.1% in the North Central Region and by 33.3% in Iowa. Other noncoterminous special districts increased by 12.7% in the U.S. and by 17.4% in Iowa.

Noncoterminous districts outside SMSA's in the U.S. showed an increase of 11.5%. In the North Central Region these districts increased by 16.4%. An increase of 26.5% characterized noncoterminous special districts in Iowa outside SMSA's. The only well-defined category of noncoterminous special, multicounty districts increased within SMSA's in the U.S. by 14.6%, by 17.8% in the North Central Region, and by 200.0% in Iowa. Multicounty districts increased outside SMSA's by 1.1% in the U.S., by 7.3% in the North Central Region, and by 26.1% in Iowa.

Coterminous and noncoterminous districts in Iowa[29]

Only one-fourth of all special districts serve an area coterminous with other local governmental units—city, county, or township. All jurisdictional classifications of special districts increased with the exception of townshipwide districts in Iowa, which, according to census data, went out of existence between 1967 and 1972.

The largest increases in Iowa were in the countywide and multicounty districts. In Iowa there is a definite trend toward more noncoterminous districts, especially with the increase in multicounty districts. Coterminous districts decreased in number between 1967 and 1972. Countywide districts increased, but in Iowa between 1967 and 1972 both citywide and townshipwide districts decreased by 44.4 and 100.0% respectively.

Special districts within SMSA's in Iowa were noncoterminous in a ratio of 5:1 when compared to coterminous districts. A decrease in the number of coterminous districts (a 20.0% reduction from 10 to 8 districts) illustrates this trend. Countywide districts in Iowa within SMSA's numbered four in 1967 and seven in 1972, an increase of 75.0% between 1967 and 1972.

Outside SMSA's noncoterminous special districts outnumbered coterminous special districts, and were increasing in number while coterminous special districts were decreasing.

The noncoterminous classification had the largest number of districts listed in both 1967 and 1972. In 1967 there were 172 special districts in this classification and 205 in 1972 in Iowa. Of these, 148 districts in 1967 and 173 districts in 1972 were listed as "other" noncoterminous districts. The remainder (24 districts and 32 districts, respectively) were listed as multicounty districts in 1967 and 1972.

Special districts coterminous with other local governmental areas listed 108 districts in 1967 and 100 in 1972. Of this total, 89 in 1967 and 95 in 1972 were categorized as countywide districts. Citywide districts accounted for nine and five of the total in 1967 and 1972, respectively. Township districts numbered 10 in 1967 and no districts were listed for 1972.

Within SMSA's Within SMSA's the noncoterminous classification had the largest number of districts listed in both 1967 and 1972. In 1967 there were 55 special districts listed in this classification and 57 in 1972. Of these, 54 districts for both 1967 and 1972 were listed as "other" noncoterminous districts. The remaining districts (1 and 3, respectively) were listed as multicounty districts.

Special districts in Iowa within SMSA's and coterminous with other local governmental areas listed 10 districts in 1967 and 8 in 1972. Of this total, four in 1967 and seven in 1972 were categorized as countywide districts. Citywide districts numbered one district in both years.

Townshipwide districts accounted for five districts in 1967 and none in 1972.

Outside SMSA's Outside SMSA's the noncoterminous classification in Iowa had the largest number of districts listed in both 1967 and 1972. In 1967 there were 117 special districts in this classification and 148 in 1972. Of these, 94 districts in 1967 and 119 districts in 1972 were listed as "other" noncoterminous districts. The remainder (23 districts and 29 districts, respectively) were listed as multicounty districts.

Special districts coterminous with other local governmental areas listed 98 districts in 1967 and 92 in 1972. Of this total, 85 in 1967 and 88 in 1972 were categorized as countywide districts. Citywide districts accounted for eight and four of the total in 1967 and 1972.

Townshipwide districts accounted for five districts in 1967 and none in 1972.

Comparision of trends in the U.S., the North Central Region, and Iowa

Districts coterminous with other local governmental units increased both in the U.S., and the North Central Region, but decreased sharply, in contrast, in Iowa. This may be an

indication that coterminous districts are not realistic means to provide services unique to Iowa's environment, or that existing local governments are not providing needed services, hence leading to the creation of special districts.

Iowa's noncoterminous district growth rate was almost twice as large as the national rate and 25.0% greater than the regional rate. Multicounty districts increased in Iowa by 33.3%, a threefold increase over the regional increase and eight times greater than the national.

Within SMSA's the rate of growth of coterminous districts decreased sharply in Iowa; whereas, the growth rate was twice as large in the North Central Region and the nation. Noncoterminous districts within SMSA's in Iowa increased at approximately eight times the U.S. and regional rates, that is, by 200.0%.

Outside SMSA's coterminous districts increased at all levels in the nation, the North Central Region, and Iowa. Noncoterminous districts increased at a rate 62% greater in Iowa than in the U.S. and the region.

Geographic size distribution in square miles of special districts[30]

Another ideal measurement of territoriality of special districts is measurement of the jurisdiction in square miles. In the U.S., the North Central Region, and Iowa, all sizes of districts increased in number fairly equally between 1967 and 1972. Approximately one-third of Iowa's special districts were greater than 400 square miles in area. The remainder of Iowa's districts were divided fairly equally among the other categories. The greatest increase between 1967 and 1972 was in districts between 100.0 and 399.9 square miles. The increase was 85.9%. Increases in the other categories varied from 20.6% to 54.0%.

In jurisdictions ranging from 36 to 99.9 square miles, from 16 to 35.9 square miles, and from 4 to 15.9 square miles, increases in Iowa were approximately twice those in the nation and the region, ranging between 33.3 and 54.0%. The number of districts with jurisdictions of 4 or less square miles in Iowa increased by 20.6%, twice the national and regional rates.

These trends are somewhat surprising. One would expect that the small districts would not increase in number but that they would decrease. One factor which makes these data less exact is the number of jurisdictions not reported. In 1967 approximately 81 out of 280 districts and, in 1972, 68 out of 305 districts did not list their jurisdictional area. The 29% and 22.3% of the districts not reporting suggest that conclusions drawn from the available data are at best tentative.

Changing population and changing numbers of special districts

Analysis reveals that 24 counties in Iowa increased in population and 75 counties decreased between 1960 and 1970.[31] During part of that period, from 1967 to 1972, there was a net increase of 25 special districts.

Of the 20 counties having both an increase in population and a change in the number of special districts, approximately one-third (seven) also had an increase in their number of special districts. Four of these increases occurred in the urban and metropolitan counties of Black Hawk, Muscatine, Story, and Webster where some of Iowa's larger cities are located. The other three counties of the seven—Delaware, Louisa, and Jasper—are more rural. These counties are adjacent to counties with larger cities. Ten counties experienced a decline in population and growth in the number of special districts. The largest urban area, Polk County, increased in population by 7.4% between 1967 and 1972, but also lost one special district.

Intercounty special districts in Iowa[32]

In addition to types of jurisdictions and jurisdictional areas, another factor descriptive of special district territoriality is the occurrence of intercounty special districts.

The location of multicounty districts in Iowa is further defined by the enumeration of the location of intercounty districts. Of all counties in Iowa with changes in intercounty units, 11 out of 12 or 91.6% of the increases in special districts were in intercounty district functions. Between 1967 and 1972 the number of counties with intercounty special districts within their county boundaries increased from 15 in 1967 to 23 in 1972. Six of the 14 counties in Iowa that had no intercounty special districts in 1967 but possessed districts in 1972 added a total of 12 new special districts. Five of these new special districts were inter-

county districts. It seems that for these intercounty special districts, there is no simple correlation between increases in the number of special districts and the increase in intercounty districts, but those counties possessing intercounty special districts in both 1967 and 1972 showed significant changes. Of counties with intercounty special districts in both 1967 and 1972, only three new intercounty special districts attributable to the formation of new special districts were added between 1967 and 1972.

Examination of financial characteristics of special districts in the North Central Region and Iowa

Revenues[33] Federal and state transfers have in effect replaced most of the local contribution to the operation of special districts in Iowa. That is, local transfers decreased by 56.6% while federal and state transfers increased by 144.5% and 26.8%, respectively.[34] Over a five-year period and allocated on a per-year basis, the revenues of Iowa's special districts increased by 1.9%, whereas the revenues of the districts in the North Central Region increased by 12.9% each year. More specifically, property tax revenues in Iowa increased by 25.1% between 1967 and 1972. In comparison, property tax revenue in the North Central Region increased by 40.5%.

Expenditures[35] Direct expenditures by special districts increased by 90.2% in the North Central Region, but decreased by 18.4% in Iowa. Clearly, regional expenditures are growing each year by approximately 18.0% in the North Central Region, while Iowa expenditures were being cut by 3.7% each year. Furthermore, special districts in Iowa are showing a trend toward spending less each year, a reverse growth pattern since expenditures in 1972 were spread over 25 more districts than in 1967. Additional data on capital outlays in both the North Central Region and Iowa indicate that Iowa's capital expenditures increased between 1967 and 1972 at approximately one-fifth the rate of such expenditures in the region.

Revenues by function[36] Within the North Central Region, when all functional types of special districts common to both Iowa and the North Central Region are totalled, the increase in revenues is 76.1% as compared to 72.9% for all functional types of special districts in the North Central Region.

Expenditures by function[37] In Iowa the changes in total expenditures between 1967 and 1972 covered a broad range, but of the 10 functional types with discernible changes, 6 were decreases. In addition, 6 of the 11 functional types of special districts common to both the North Central Region and Iowa showed increases of over 50.0% in the North Central Region between 1967 and 1972.

Total revenue and total expenditure by function[38] Changes in revenues outdistanced changes in expenditures considerably in the North Central Region for the functional areas of cemeteries, fire protection, highways, flood control, natural resources (other and composite purposes), and sewerage. Other functions in the North Central Region—those with changes in revenues nearly equal to changes in expenditures—were libraries, drainage, and irrigation. Those functions in the North Central Region where changes in expenditures outdistanced changes in revenues were education, health, hospitals, housing and urban renewal, soil conservation, parks and recreation, "other," and utilities.

Within Iowa those functions with a large decrease or a large increase in revenues included the functions of highways, libraries, drainage, flood control, and water supply. In general, with exception of fire protection, sewerage and soil conservation districts, district expenditures of each functional type were sharply decreasing in Iowa, that is, with decreases ranging from 7.7% to 61.5%. At the same time, revenues in Iowa in some of these same functional types were increasing by 24.5, 42.9, and 113.0%. When the greatest increases in expenditures were ranked in Iowa, sewerage was first; fire protection, second; and soil conservation, third. In the region the three functional types of special districts with the greatest increase in expenditures are utilities, housing and urban renewal, and water supply. These are totally different between the region and Iowa.

Indebtedness[39] In Iowa long- and short-term debt decreased substantially; in the North Central Region both long- and short-term debt increased substantially. Significantly, long-term debt in Iowa between 1967 and 1972 decreased by 42.7% and short-term debt decreased by 75.0%. All indications are that special districts in Iowa have been spending less and have been rapidly getting out of debt. In contrast, the North Central Region has been steadily increasing its debt, with twice as much emphasis on short-term debt as on long-term debt.

Examination of the role of special districts in SMSA's[40]

Analysis of special districts within and outside SMSA's in Iowa shows that no type of district function in Iowa increased in number totally within SMSA's, but that the functions of library, flood control, and drainage districts increased totally outside SMSA's. Decreases occurred only in districts outside SMSA's and included districts for health and water supply, both of which decreased in number by nearly 50.0%.

The number of sewerage districts increased by the same percentage within and outside SMSA's. Sewerage districts grew in number perhaps as a response to the availability of federal funds. Fire protection districts grew faster outside SMSA's than within SMSA's. Overall, a rural and small-town image shadows the growth patterns of special districts in Iowa. This is especially true because provision of typically urban services by special districts has not been accentuated within SMSA's since the growth in the number of special districts has occurred outside SMSA's.

Approximately one-fifth of Iowa's special districts (65 of 280 special districts in 1967 and 65 of 305 in 1972) were located in SMSA's.

Iowa's library districts accounted for 10.0% in 1967 and 25.0% in 1972 of the total number of library districts in the nation within SMSA's, with population ranging from 50,000 to 99,999. The four drainage districts in Iowa within SMSA's with population ranging from 50,000 to 99,999 constituted 8.7% and 12.1% of the total U.S. districts of the same SMSA size in 1967 and 1972, respectively. Soil conservation districts in Iowa numbered three in both 1967 and 1972, 12.0% and 20.0% of the total U.S. districts of the same 50,000 to 99,999 size classification.

Iowa's drainage districts in SMSA's with a population ranging from 100,000 to 199,000 constituted 2.2% and 1.8% in 1967 and 1972 of the total U.S. districts of the same size. Iowa's four soil conservation districts constituted 4.1% of the total U.S. districts of the same SMSA size. Sewerage districts in the same size SMSA constituted 1.8% and 4.4% of the total U.S. districts of the same SMSA size. Within Iowa's SMSA's of 100,000 to 199,999 population, library districts numbered two in both 1967 and 1972 and constituted 10.5 and 7.7%, respectively, of the total U.S. districts of the same SMSA size. The 11 fire protection districts listed in 1967 and 10 listed in 1972 constituted 6.5 and 3.2%, respectively, of the total U.S. districts of the same size class in 1967 and 1972.

Iowa's only SMSA in the 200,000 to 299,999 category is Polk County. The number of SMSA's in Iowa of the class constituted 1.5% nationally in both 1967 and 1972. Thirty-four utility districts were listed in 1967 and 33 in 1972 for this Iowa SMSA. They constituted 18.2% in 1967 and 21.0% in 1972 of the total U.S. special districts of this SMSA size.

In both 1967 and 1972, one sewerage district was present in the Polk County SMSA and represented 0.9% in 1967 and 1.1% in 1972 of the total U.S. districts of the same SMSA class. The one Iowa soil conservation district in this SMSA class constituted 1.7 and 1.3% of the total U.S. districts of the same SMSA size.

SUMMARY OBSERVATIONS

A variety of points emerge from this study. In the first place, in recent decades the growth in numbers of special districts has outpaced the growth of all other local governments, even while recognizing the enormous reduction of one type of special district—the school district—since 1950. All indications are that the growth trend will continue, traceable in part to action by special interest groups recognizing the variety of benefits that can accrue to the group through a judicious construction of certain types of governmental districts.

Another key development to be recognized is that many of the new districts are intercounty districts. In Iowa, for example, about one-half of those recently established cross county lines. This trend illustrates once again that the need for local governmental services transcending traditional county governmental boundaries is not limited to the megalopolis, but is persistently present in rural and agriculturally oriented regions as well.

Moreover, the federal nature of our system nationally has played an important part in both the growth and nature of special districts, particularly in the last decade. Federal and state dollars replaced much of the local contribution to special districts between 1967 and 1972. In addition, there occurred a substantial growth in the number and type of districts where federal funding existed to encourage them, such as in the areas of housing, urban renewal, sewerage, and flood control.

Nonetheless, the growth trends of special districts in Iowa between 1967 and 1972 differed sharply from those exhibited in the nation generally as well as in the North Central region. At the national and regional level, special district growth was equally divided between urban and larger urban areas classified by the Bureau of Census as Standard Metropolitan Statistical Areas (SMSA's). In Iowa, on the other hand, the growth in special districts occurred almost entirely outside the boundaries of SMSA's. The new districts in Iowa are located in rural and semirural areas, but they provide essentially urban services.

At first glance, then, the special districts in Iowa might appear to be seeking to bring some of the advantages of city living to the country. In fact, however, the growth in special districts stresses certain natural resource functions such as drainage in addition to flood and fire control for the rural areas and the smaller communities that they serve. In contrast, nationally and in the North Central region, the growth in services provided by special districts stressed more immediate personal services such as health and mass transportation.

Another noteworthy feature regarding special districts in Iowa is that they are rapidly abandoning classic county and township boundaries, which have in earlier years constituted the parameters for special district operation. Instead, the boundaries of the new special districts in Iowa are increasingly being defined by regional or ecological characteristics more relevant to the functional requirements of the district.

Another area in which the Iowa special districts differ from their counterparts both in the North Central region and nationally is in respect to bonded indebtedness. While special districts both nationwide and in the North Central region are increasing their indebtedness substantially, both the long- and short-term indebtedness of Iowa special districts is being rapidly reduced. Furthermore, Iowa's special districts show no trend or tendency to finance service through substantial borrowing.

An interesting sidelight to the financial operation of special districts in Iowa between 1967 and 1972 is revealed by the fact that though the number of districts in the state increased noticeably, the total level of expenditures decreased. This phenomenon suggests either a slackening of certain district functions or a remarkable degree of frugality almost unthinkable in this era of escalating costs.

An equally interesting and related development in Iowa can be seen in the data indicating that not only are Iowa's special districts spending less, but that they are also filling their coffers with revenues substantially in excess of expenditures. This almost embarrassing state of affluence may be traced in part to statutory grants of fiscal independence through taxing powers in excess of amounts realistically necessary today, or in some instances to simply overcharging for services rendered.

Nonetheless, what may well be the single most salient feature to emerge from the 12% growth in the number of special districts between 1967 and 1972 in Iowa, the North Central region, and the nation generally is the trend indicating that more and more special district governments are being formed where local units of government will not or cannot provide needed services because of bureaucratic inertia and insensitivity or because of constitutional or statutory restrictions.

FOOTNOTES

[1] One of the more curious features of American civilization in the Twentieth Century is that major changes in the demographic and socioeconomic characteristics of the nation have not been followed by corresponding alterations in the basic forms of local governmental units. Thus, the population shift from rural farms to the cities began to be clearly observed with the official closing of the frontier in 1890 and crested to such a wave in the last several decades that, at best, a scant 7% of the population is presently classified as rural-farm, even with the liberal application of this term as permitted by the definition of the Bureau of the Census. Despite this clear change in reality, the geographical size of the county (the basic unit of local government in most of the U.S.) has not varied from that time in history when it was designed to permit a typical American—a farmer, then—to travel by horse and buggy from his farm to the county seat and back to his farmstead in one day.

[2] More detailed discussions of legal and organizational aspects are contained in: Donald E. Boles, "Special Governmental Districts in the 1970's: A Study in Legal Legerdemain and Political Palliatives," *Iowa State Journal of Research*, 48: 339-354, May, 1974; and

John C. Bollens, *Special District Government in the United States*, University of California Press, Berkeley, 1957.

[3] A completely satisfactory definition of the term Special Districts is lacking, but there is some general agreement on some of the elements that provide the essence of Special Districts. See: S. J. Makielski and D. G. Temple, *Special Districts Government in Virginia*, Institute of Government, University of Virginia, 1967, p. 5.

[4] See: "Legal Nature of Public Purpose Authorities: Governmental, Private, or Neither?" 8 *Georgia Law Review* 680 (Spring, 1974); T. E. Borcherding and R. T. Deacon, "Demand for the Services of Non-Federal Governments," *American Economics Review*, 62: 891-901, December, 1972; R. M. Belmonte, "State and County Relationships: An Imperfection in the Fabric of American Federalism," *Public Administration Review*, 33: 561-563, November, 1973.

[5] See: B. F. Hillenbrand, "Counties: The Emerging Force," *American Academy of Political and Social Science Annals*, 416: 91-98, November, 1974; "Urban County—Kentucky's New Structure for Local Government," 62 *Kentucky Law Journal* 568 (1973-1974).

[6] These are some of the titles referring to special districts as listed in: Advisory Commission on Intergovernmental Relations, *Regional Decision-Making: New Strategies for Substate Districts, Vol. I, Substate Regionalism and the Federal System*, (Washington, D. C.: U.S. Government Printing Office, October, 1973), p. 20.

[7] See discussion of Criteria for Classifying Governmental Units, U.S. Bureau of the Census: 1967, Vol.I, *Governmental Organization*, (Washington, D. C.: U. S. Government Printing Office, 1968), p. 13. One of the more comprehensive definitions of Special Districts has been offered by Professor John C. Bollens. He suggests that Special Districts are "organized entities, possessing a structural form and official name, perpetual succession, and the right to sue and be sued, to make contracts and to obtain and dispose of property. They have officers that are popularly elected or chosen by other public officials. They have a high degree of public accountability. Moreover, they have considerable physical and administrative independence from other governments." The financial and administrative criteria, Bollens feels, distinguish Special Districts and other governments from all dependent or subordinate districts and from most authorities that, lacking one or both of these standards, are not considered governmental units. See John C. Bollens, *Special District Government in the United States*, University of California Press, Berkeley, 1957. The definition used by the Bureau of the Census parallels Bollens' definition.

[8] Some authorities and various state supreme courts do not accept all of Bollens' criteria, particularly those suggesting that special districts have the quality of a public municipal corporation with the right to sue and be sued. The high courts of various states have held that a variety of generally recognized types of special districts are only quasi-municipal corporations with definitely restricted powers and liabilities. Fire Districts, for example, were held to be of this character by the Massachusetts Supreme Court (Williams College v. Williamstown, 219 Mass. 46, 106 N. E. 687, 688), and Road Districts have been classified as quasi-public corporations by state high courts in some states such as Louisiana [Farmer v. Myles, 106 La. 333, 30 So. 858; California, San Bernardino Ct. v. South Pacific Railway Co., 137 Cal. 659, 70 P. 782; Nebraska, Madden v. Lancaster County, 65 F. 191, (1894); Iowa, White v. Road District No. 1, 9 Iowa 202 (1859)].

Indeed, the Iowa Supreme Court in 1859, in what seems to be its first encounter with the concept of special districts, held that even though the Iowa statutes provided specifically that each road district was to be responsible for all damages sustained by a person in consequence of defects in the roads or bridges in the district, the districts could not, in fact, be treated as a public corporation and could not, in this case, be sued for the value of a horse injured in falling through a bridge. The Iowa Court went even further and held that a road district could not be a party to an action in a court as a corporation, quasi or otherwise, since no statute made them a body corporate, capable of suing and being sued (9 Iowa 202, 1859). In 1971, however, the Iowa Court modified that extreme approach to special districts and held that drainage districts, at least, are political subdivisions of a county, and that in Iowa (as is true in most other states) the county is held to be a quasi-public corporation and not subject to the legal liabilities or granted the general powers held by a public municipal corporation. Moreover, the Iowa Court has held consistently in a number of cases that drainage districts are not a legal utility or a public corporation.

Thus, they cannot be sued nor incur corporate liability; they have only characteristics of their own, not the powers granted to cities and towns or possessed by private individuals.

Later, Iowa law reflects a fine example, however, of how confusion is compounded over the legal status of special districts and their governmental and corporate position. The statutes concerning the creation of Soil Conservation Districts state flatly that, "The district shall be a body corporate. . ." (Iowa Code, 1971, 467A.5 and 6). Moreover, in some of the most recently enacted legislation—that creating the six major watershed Conservancy Districts in 1971—the Iowa statutes provide, "In the furtherance of the objectives set forth in Section 467D.1, the entire State of Iowa shall be divided into six Conservancy Districts, and the same shall hereby be established as political subdivisions of the state. . ." (Iowa Code, 1971, 467D.3). See: Donald E. Boles, "Special Governmental Districts in the 1970's: A Study in Legal Legerdemain and Political Palliatives," *Iowa State Journal of Research*, 48: 339-354, May, 1974.

[9] See: Michael J. Huston, "Special Service Districts in a Consolidated City-County: Conflict Between Metropolitan Reform and 'One Man-One Vote' in Indianapolis-Marion County," 47 *Indiana Law Journal* 101 (1971); "Role of Citizen Advisory Boards in Administration of Natural Resources," 50 *Oregon Law Review* 153 (Winter, 1971); J. T. Mitchell, "Use of Special Districts in Financing and Facilitating Urban Growth," 5 *Urban Lawyer* 185 (Spring, 1973); "Voter Restrictions in Special Districts: A Case Study of the Salt River Project," 1969 *Law and Social Order* 636 (1969).

[10] Data are taken from: U. S. Bureau of the Census, Census of Governments: 1967, Vol. I, *Governmental Organization*, (Washington, D.C.: U.S. Government Printing Office, 1968); and Census of Governments: 1972, Vol. I, *Governmental Organization*, (Washington, D.C.: U.S. Government Printing Office, July, 1973), Table 6. Local Governments Inside and Outside SMSA'a by Type and by State: 1967 and 1972.

[11] Data are taken from: U.S. Bureau of the Census, Census of Governments: 1972, Vol. I, *Governmental Organization*, Table 1. State and Local Governments by Type and by Region: 1942 to 1972.

[12] See: J. C. Strouse and P. Jones, "Federal Aid: The Forgotten Variable in State Policy Research," *Journal of Politics*, 36: 200-207, February, 1974.

[13] See: J. T. Mitchell, *op. cit.*; "Urban County—Kentucky's New Structure for Local Government," 62 *Kentucky Law Journal* 568 (1973-1974); T. E. Borcherding and R. T. Deacon, *op. cit.*; and Michael J. Huston, *op. cit.*

[14] U. S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 15. Special Districts Within and Outside SMSA's by State: 1967 and 1972.

[15] From one viewpoint the geographic form and multijurisdictional coverage of many counties encompassing as they do municipalities and townships theoretically could give counties exceptional potential for guiding and serving the new metropolitan growth expanding from the central cities and older suburbs. Most counties are, however, rural-farm throwbacks to the 19th Century courthouse style of government that earned them the reputation in textbooks as "The Dark Continent of American Politics." This seems clearly to be the case in Iowa. Donald E. Boles, "Special Governmental Districts in the 1970's: A Study in Legal Legerdemain and Political Palliatives," *Iowa State Journal of Research*, 48: 340, May, 1974; See: Michael J. Huston, *op. cit.;* "Voter Restrictions in Special Districts: A Case Study of the Salt River Project," 1969 *Law and Social Order* 636 (1969).

[16] With regard to the role of the county as the central unit of services and to intercounty merger of functions, the outlook appears bleak for such revision and cooperation. In recent years one hopeful development in modernizing county officials' views of the county in the 1970's can be found in the growing vigor of the National Association of Counties based in Washington, D.C. With the enormous increase in federal programs involving local governmental units in the 1960's, an important job of NACO has been providing county officials with up-to-date information on the more than 500 different federal aid programs and the techniques required to pick one's way through the various agencies typically responsible for administering them. In 1970 the bulk of NACO's income came from membership fees and government contracts. With the strength of NACO there seems little likelihood at present that any significant desire exists among Americans to change notably their geographic boundaries or characteristics. *The Near*

Side of Federalism: Improving State and Local Government, Ford Foundation, January, 1972, pp. 26-30. Also statutory devices designed to help particularly rural counties with sharply declining population have proved in practice to go singularly unused by most of the affected counties. This is the authorization to permit the merging of county offices within a single county. In Iowa, for example, where this has been permitted since 1959, the sole attempt in the state by the citizens of Mahaska County to accomplish the consolidation of some of its county's offices was decisively defeated. Donald E. Boles, "Special Governmental Districts in the 1970's: A Study in Legal Legerdemain and Political Palliatives," *Iowa State Journal of Research*,48: 340-341, May, 1974.

17 Perhaps one reason why special districts have been formed is the need for special profession or administrative attention to certain functions that are not easily handled by the county structure. According to the Ford Foundation, only 45 counties have fulltime elected executives comparable to mayors or governors. The study found that the majority of American county governments lack adequate professional staff. Moreover, the county supervisors or commissioners who run most of our counties make their living primarily as farmers, clerks, insurance brokers, or small businessmen, and their elected jobs are typically avocations. *The Near Side of Federalism: Improving State and Local Government*, Ford Foundation, January, 1972, pp. 26-30. This is noted not to suggest that county supervisors are not representative of their constituencies, but to stress that they commonly lack the needed technical knowledge as well as the time necessary to acquire such knowledge on their own and to keep abreast with counties' changing problems.

18 See: J. C. Strouse and P. Jones, *op. cit.*

19 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 15. Special Districts Within and Outside SMSA's by State: 1967 and 1972.

20 See: R. E. Beck and B. E. Bohlman, "Drainage Law in North Dakota: An Overview," 47 *North Dakota Law Review* 471 (Summer, 1971).

21 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 15. Special Districts Within and Outside SMSA's by State: 1967 and 1972.

22 See: Water Control and Improvement District: Concept, Creation, and Critique, 8 *Houston Law Review* 712 (March, 1971).

23 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 15. Special Districts Within and Outside SMSA's by State: 1967 and 1972.

24 *Ibid.*

25 *Ibid.*

26 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 15. Special Districts Within and Outside SMSA's by State: 1967 and 1972.

27 *Ibid.*

28 *Ibid.*

29 *Ibid.*

30 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 16. Geographic Size Distribution of Special Districts by State: 1967 and 1972.

31 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 21. Local Governments and Public School Systems in Individual County Areas: 1967 and 1972.

32 *Ibid.*

33 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. 4, *Government Finances*, Number 2, Table 3. Revenue of Special Districts by Type and Source: 1966-67 and 1971-72; Table 4. General Revenue of Special Districts by Source: 1966-67 and 1971-72.

34 See: J. C. Strouse and P. Jones, *op.cit.*; B. F. Hillenbrand, *op. cit.*

35 Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. 4, *Government Finances*, Number 2, Table 6. Expenditures of Special Districts by Character and Object by States: 1967 and 1972.

[36] Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. 4, *Government Finances*, Number 2, Table 13. Revenue, Expenditures and Debt of Special Districts by Function and by Area Served: 1967 and 1972.

[37] *Ibid.*

[38] *Ibid.*

[39] *Ibid.*

[40] Data are taken from: U.S. Bureau of the Census, Census of Governments: 1967 and 1972, Vol. I, *Governmental Organization*, Table 18. Summary of Local Governments and Public School Systems in SMSA's by Population Size of Area: 1967 and 1972.

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Political Science
No thesis

RICKERL, DIANE HOLLAND
Applied Art (Craft Design)
Designing a cylindrical loom and executing experimental works

SCHROEDER, NAN EMMA
Applied Art (Craft Design)
The weaving of original textiles influenced by pre-Columbian Peruvian weaving

SEROVY, ANITA MORIN
History
Charles Dickens and the image of America
SIANO, ELIZABETH ANN MOORE
English
Feminist politics and film criticism in Women and Film
SMITH, MARIAN GAY
English
The anatomy of a novel: Plot structure in Raintree County
SMITH, SUSIE
History
A review and analysis of the political careers of Adam C. Powell and Shirley Chisholm
STENSVAAG, JAMES THOMAS
History
The treatment of minority groups in radical journals, 1900-1920
VONDEHAAR, MARGARET RACHAEL
English
Bidialectalism—the conflict 1949-74
WALTER, LINDA GALE
English
Raindust: A volume of Black poetry
WILLATT, BEVERLEY JOY
General Graduate Studies
No thesis

MASTER OF ENGINEERING

BAIRD, THOMAS CHARLES
Electrical Engineering
No thesis
CHOOBINEH, FARROKH
Industrial Engineering
No thesis
CLAYTON, RICHARD MARTIN
Industrial Engineering
No thesis
EIDE, MICHAEL CECIL
Engineering Mechanics
No thesis
FOSS, THOMAS WAYNE
Industrial Engineering
No thesis
GAMBOA, CRISTOBAL SILVA
Electrical Engineering
No thesis
GEBHARDT, MICHAEL EDWARD
Industrial Engineering
No thesis
GLOMSKI, GARY JOSEPH
Industrial Engineering
No thesis
LAUDERBAUGH, STEPHEN D.
Industrial Engineering
No thesis
MOGHARI, MOHAMMAD
Nuclear Engineering
No thesis
SHEWSKI, MICHAEL JAMES
Nuclear Engineering
No thesis

WORMLEY, SAMUEL JAMES
Electrical Engineering
No thesis
YOVONIE, ROWLAND ANDERSON
Industrial Engineering
No thesis
YUNAS, SYED MAQBOOL
Electrical Engineering and Industrial Engineering
No thesis

MASTER OF LANDSCAPE ARCHITECTURE

CHOI, KEY SOO
Landscape Architecture
An analysis of the exterior space in the urban structure
DELONG, DOUGLAS ALEXANDER
Landscape Architecture
No thesis
ENGER, CHRISTOPHER MARK
Landscape Architecture
No thesis
OHLERKING, DAMON HAROLD
Landscape Architecture
No thesis

MASTER OF SCIENCE

ABRAHAM, KENNETH FLOYD
Wildlife Biology
Waterbirds and oil-contaminated ponds at Point Storkersen, Alaska
AKIN, DONALD RAY
Statistics
No thesis
ALAVI, SEYED FRUHAR
Industrial Relations
No thesis
ALDERS, CLARENCE DEAN
Statistics
No thesis
AL-JALIL, HAMID FADHIL
Agricultural Engineering
Design and performance of a spring-damper device for controlling plow lateral cutting angle
ALLEN, KAREN CLARK
Child Development
Social competency in trainable mentally retarded children and maternal behavior
AMUNDSON, DIANE LEE
Family Environment
Costs and usage patterns of household utilities by elderly Iowans
ANDERSON, BARBARA JEAN
Home Economics Education
Verbal interaction and learning environment in the classrooms of first-year home economics teachers
ANDERSON, DAVID MORRIS
Bacteriology
Relationship of chemotaxis to swarming of *Proteus mirabilis*
ANDERSON, JACK FRANCIS
Education (Educational Administration)
No thesis
ANDREWS, WAYNE NOEL
Entomology
Transovarial transmission of trivittatus virus in the mosquito, *Aedes trivittatus*

ANDREWS, WELLS FREDERICK
Soil Morphology and Genesis
No thesis

ARABABAN-GHAFOURI, MOHAMMAD TAGHI
Animal Production
No thesis

ARCHILLA, DORIS ANN
Computer Science
No thesis

ARENDS, WILLIAM LOUIS
Statistics
No thesis

ASIF, MOHAMMAD
Plant Breeding
No thesis

BAGHI, HEIBATOLLAH
Education (Adult and Extension Education)
No thesis

BAIR, CRAIG WILLIAM
Food Technology
Yolk cholesterol in various avian species

BAKER, BARBARA BELL
Home Economics Education
Competencies needed for tasks performed by alteration specialists and fabric specialists

BALDUS, ROBERT LARRY
Industrial Education
No thesis

BALLARD, DENNIS DEAN
Sociology
Socioeconomic status and youth attitudes toward community and community agencies

BARISAS, SUSAN GAIL
Water Resources
Effect of tillage systems on nutrient loss in runoff

BARRON, DONALD JOSEPH
Statistics
No thesis

BARRY, MICHAEL WRAY
Entomology
Developmental variation in the male and female Oriental rat flea, Xenopsylla cheopis (Rothschild, 1903)

BARTUAL, RAFAEL
Plant Breeding
Estimation of genetic variances in BSSS by use of unselected maize inbred lines developed by full-sib mating

BEHRENS, ALAN MICHAEL
Industrial Engineering
Technological forecasting applied to water resource planning

BERAN, CAROLYN BROWN
Home Economics Education
Task validation for Iowa homemaker—home health aides

BIBLE, GARY GILL
Geology
Geologic and engineering properties of quaternary age materials at the Scranton II roadcut, Scranton, Iowa

BLACK, ELIZABETH SEYFARTH
Physics
Optical properties of Nb-Mo and other alloys of Nb with its nearest neighbors in the periodic table

BLOETHE, WILLIAM GAYLAND
Electrical Engineering
Application of a boiler model to transient stability studies of an electric power system
BOGGESS, EDWARD KEITH
Wildlife Biology
Some population parameters of Iowa coyotes and an analysis of reported livestock losses
BOLOORFOROOSH, MOHSEN
Economics
No thesis
BOOTH, KENNETH KURT
Veterinary Anatomy
The angioarchitecture of the canine thyroid gland
BORDELON, EUGENE PAUL
Computer Science
Explicit declaration of parameter directionality in programming language design and implementation
BOWEN, SUSAN CHRISTINA
Family Environment
Self-sufficiency in household tasks of rural nonfarm elderly
BOWMAN, ELIZABETH A. WATTS
Education (Guidance and Counseling)
No thesis
BOYCE, BRUCE MAXWELL
Industrial Relations
No thesis
BRADBURY, WILLIAM LAWRENCE
Sanitary Engineering
Treatment of a colored industrial wastewater with granular activated carbon
BRAVO, HUGO VASQUEZ
Mechanical Engineering
Limits of heat transfer in liquid-filled enclosures
BRESLER, ANN FRANCES
Family Environment (Housing)
Residential crowding, fertility limitation, and the propensity to move
BRETL, ROBERT FRANCIS
Computer Science
No thesis
BROCKWAY, TANYA KLAR
Sociology
An elaboration, evaluation, and test of Rosow's model of adjustment
BRODERICK, CYRIL EMERY
Crop Production and Physiology
The effects of several plant growth regulators on root growth and development of *Glycine max* (L.) Merrill
BROOKS, DAVID PRICE
Structural Engineering
No thesis
BROWN, ANN CAROLINE
Education (Curriculum and Instructional Media)
Student evaluations of instructors as possible criteria for effective teachers
BROWN, NANCY LOUISE
Education (Guidance and Counseling)
No thesis
BUFORD, LINDA ELIZABETH
Family Environment
Sanitation in self-service laundry equipment

BURNETT, JOHN MICHAEL
Water Resources
Testing the reliability of grab sampling for river water surveys
BURNS, RANDALL LOUIS
Agricultural Economics
No thesis
BUSBY, GARY LLOYD
Education (Guidance and Counseling)
No thesis
BUTLER, DOUGLAS LEE
Transportation Engineering
An analysis of rural public transportation in Iowa
CABLE, JAMES KARL
Transportation Engineering
No thesis
CAIN, PATRICK R.
Transportation Engineering
No thesis
CAMERON, WILLIAM SCOTT
Sanitary Engineering
Effect of chlorine on nitrogenous oxygen demand
CAREY, JAMES ROBERT
Entomology
Overwintering and cold-hardiness investigations on the black cutworm, Agrotis ipsilon (Hufnagel)
CARLSON, EDD W.
Agricultural Education
No thesis
CARTER, JAMES CHARLES
Soil Microbiology and Biochemistry
Recovery of an inoculated strain of *Rhizobium japonicum* from nodules of field grown soybeans affected by inoculation rates and applied nitrogen
CHAIKA, JOHN JONATHAN
Fisheries Biology
Recurrent group analysis of small demersal cichlid species of Lake Malawi and its possible ecological implications
CHANG, JORGE FRANCISCO
Crop Production and Physiology
Performance of semideterminate and indeterminate soybean isolines
CHELSVIG, KATHLEEN ANN
Sociology
Recidivism in juvenile delinquency: An examination of social and psychological variables relating to prediction
CHEN, PATRICIA PEI
Zoology (Physiology)
The influence of a urinary pheromone on the estrous cycle of the Mongolian gerbil
CHEN, JENGRONG JAMES
Statistics
No thesis
CHOU, KAN-SEN
Chemical Engineering
A study of the extractability of alumina from fly ash by the lime-sinter process
CHRISTIANSEN, STEVEN MARK
Electrical Engineering
A digital waveform generator for music synthesis
CLAASSEN, WILLIAM JOHN
Sanitary Engineering
Analysis of alternative flood control policies at Saylorville Reservoir

CLARK, JOHN ALVIN
Education (Adult and Extension Education)
No Thesis
CLARKSON, BRENDA CELESTE
Statistics
No thesis
CLEGG, JANET KAY
Education (Curriculum and Instructional Media)
Development of computer assisted instruction in photography on Plato
CLIFTON, LORETTA ELIZABETH
Institution Management
Practices and conditions in two vending systems in relation to microbiological quality and safety of food
COFFMAN, DICK L.
Agricultural Economics
Alternative long run financial implications for the local multi-enterprise farmers cooperative elevator under varying levels of growth and capital rationing
COLEMAN, LLOYD WILBERT III
Botany (Physiology)
The effect of sodium bisulfite on *Avena* coleoptile growth
COLLIAS, KAREN JOYCE
General Graduate Studies (Biological Sciences)
No thesis
CONLEY, MAUREEN CLAIR
Nutrition
Effect of added protein or amino acids on iron utilization in iron depleted rats
COWLES, SUSAN MILLER
Education (Learning Disabilities)
No thesis
CRAMER, WALTER JOSEPH, Jr.
Mathematics
No thesis
CROSBIE, THEODORE M.
Plant Breeding and Cytogenetics
Variability for net photosynthesis in Iowa Stiff Stalk Synthetic and relationship of net photosynthesis with various plant traits
CROWLEY, THOMAS C.
Town and Regional Planning
Grants-in-aid Urban vs. rural allocation
CUNNING, VIRGINIA K. FISHER
Sociology (Anthropology)
Ethnicity in a midwestern city: An anthropological investigation of the Greeks in Des Moines
DAHAB, MOHAMMED FITURI
Sanitary Engineering
Single-medium, unstratified-bed filtration of secondary effluent
DAHLBERG, KURT ROBERT
Molecular, Cellular and Developmental Biology
Selected aspects of spore germination in the Myxomycete, Fuligo septica (L.) Wiggers
DALHOFF, RANDAL FRED
Computer Science
No thesis
DALSTED, ELIZABETH ANN
Education (Adult and Extension Education)
No thesis
DAMMAN, STEVEN EUGENE
Industrial Education
No thesis

D'ANGELO, LOIS JEANNE
Journalism and Mass Communication
A man and his magazine
Sixty-three years of the Northwestern Banker: Its publisher; Its audience; The times
DARNELL, DAVID F.
Education (Educational Administration)
No thesis
DARWICH, NESTER ALEJANDRO
Soil Fertility
Indices of soybean growth in the field as affected by soil phosphorus level
DAVIES, LINDA ERICKSON
Family Environment
The effects of social role loss in widowhood
DAVIS, RICHARD STANLEY
Sociology
Participation in complex organizations: An empirical application of general systems theory
DEBRUIN, RODNEY HAROLD
Geology
Precambrian geology near Bruce Mountain, northern Bighorn Mountains, Wyoming
DELGADO, MARIO EULOGIO
Economics
No thesis
DESAI, ANAND SHASHIKANT
Chemical Engineering
The effect of temperature on the resistivity of fluidized carbon beds
DESIDERI, JEAN-ANTOINE
Aerospace Engineering
Over-relaxation of a finite-difference technique to solve fluid flow problems
DEUTSCH, CONNIE JEAN
Psychology
Sex role stereotypes: Effect on perceptions of self and others, and on personal adjustment
DEVEAUX, HILLARY HUGH
Economics
No thesis
DISHON, GERALD R. II
Physics
Redshifts and superluminal velocities
D'SILVA, BRIAN CHRISTOPHER
Economics
No thesis
DUNSETH, DALE WAYNE
Physiology of Reproduction
Fetal development during restriction of dietary intake in the pig
EBERHART, RICHARD BRUCE
Mechanical Engineering
No thesis
EHRFURTH, PAUL WARREN
Town and Regional Planning
The Housing and Community Development Act of 1974: A nationwide survey of planning directors and city managers
EINCK, KATIE EGGLETON
Molecular, Cellular and Developmental Biology (Genetics)
Genetic mapping of a strain of *Escherichia coli* temperature sensitive for control of RNA synthesis
EINCK, LEO
Zoology (Developmental Biology)
Synthesis and incorporation of lipid into membranes of cleaving sea urchin embryos

ELLIOTT, ALAN LEE
Plant Breeding and Cytogenetics
Inheritance of traits in inter and intraspecific oat crosses

ENGEL, RAYMOND EDWARD
Chemical Engineering
Desulfurization of calcium sulfate in a two zone fluidized bed reactor

ENGLE, LAWRENCE EUGENE
Soil Engineering
Application of bore-hole shear for in situ shear strength of soft rock

ERICKSON, PAUL NORMAN
Industrial Relations
No thesis

ESCAMILLA, EMILIO
Soil Fertility
Economic criteria for nitrogen fertilization of corn in relation to moisture stress in continuous corn culture

EUCHER, RALPH CRAIG
Industrial Relations
No thesis

FAKOREDE, FLORA OMOLARA
Education (Guidance and Counseling)
No thesis

FAKOREDE, MORAKINYO ABIODUN BAMIDELE
Plant Breeding
Productivity of maize *(Zea mays* L.*)* as affected by plant density and simulated vertical leaf orientation

FAPPIANO, LAWRENCE ALEX
Industrial Relations
No thesis

FARR, WILLIAM JESSE
Geodesy and Photogrammetry
No thesis

FILOSA, LOUIS GERARD
Biomedical Engineering and Chemical Engineering
Analysis of mass transfer dynamics and energy requirements associated with human kidney function

FISCUS, RONALD RAY
Physiology
Effects of parathion on steady-state levels and turnover of norepinephrine and dopamine in selected regions of rat brain

FITCH, DAVID PAUL
Industrial Relations
No thesis

FITCH, WILMA ALIX FRASER
General Graduate Studies (Arts and Humanities)
No thesis

FITZ, MARION JOYCE MAXWELL
General Graduate Studies
No thesis

FITZGERALD, BONNIE LEWIS
Education (Adult and Extension Education)
No thesis

FOSS, CAROLYN JUNE KOVALIK
Child Development
Children's self-concept and perception to parents' behavior

FOUSER, THOMAS J.
Computer Science
No thesis

FUQUA, ROBERT WESLEY
Psychology
Organization and retrieval capacity in learning from prose
GADBURY, NEIL DOUGLAS
Journalism and Mass Communication
A study of the effect of humor on retention of broadcast advertising messages
GAHRING, SHERRI ANN
Textiles and Clothing
Consumers' interpretations of permanent care labels
GALLENTINE, ROGER JAY
Industrial Relations
No thesis
GAMA, ELTO EUGENIO GOMES E
Plant Breeding and Cytogenetics
Relationship between inbred and hybrid performance in maize
GARNETT, TOMMY
Rural Sociology
The impact of industrialization upon level and distribution of income among small communities in Iowa 1960-1970
GERDOM, DONALD HENRY
Education (Guidance and Counseling)
No thesis
GIBSON, CRAIG DEXTER
Agricultural Economics
An economic model for deriving economic values for use in selection indexes
GILL, RICHARD WARREN
Education
No thesis
GILLISPIE, ARDYTH HARRIS
Nutrition
Design and pre-test of a communication system for changing food behavior
GINAPP, NANCY KAYE JOHNSTON
Education (Guidance and Counseling)
No thesis
GINGERICH, RICHARD GEOFFREY WARMINGTON
Inorganic Chemistry
Thioketone and mercapto complexes of chromium and tungsten carbonyls
GIRARD, EMILE LOUIS
Horticulture
No thesis
GIRGUS, ANDRE
Soil Morphology and Genesis
Soil landscape relationships in a small watershed area of Marion County, Iowa
GLADITSCH, THOMAS CHARLES
Education (Higher Education)
No thesis
GLANVILLE, THOMAS DEAN
Sanitary Engineering
Optimal operation of a flood control reservoir
GLASS, JOHN DELMAS
Geodesy and Photogrammetry
No thesis
GOETTSCH, JANE ROSENHAUER
Sociology
The ideology of rape: An analysis of the meanings system reactors attach to rape, the rapist, and the rape victim
GOLDEN, BRUCE M.
Analytical Chemistry
Analytical lines for long-path infrared absorption spectrometry of air pollutants using diode lasers

GOMEZ, SANTIAGO LUIS
Statistics
No thesis

GONEN, DOROTHY JEAN MUFFETT
Food Science
The influence of water activity on myoglobin catalysis of lipid oxidation in beef and model systems

GOODYEAR, RICHARD LEE
Mechanical Engineering
No thesis

GRIGSBY, MARK EDWIN
Animal Nutrition
Effect of restricting dietary calories or protein and refeeding on skeletal muscle development and plasma hormone levels in the young rat

GRINTON, PHILIP CHARLES
Geodesy and Photogrammetry
No thesis

GROBEN, JEAN CLURE
Family Environment
Sex role stereotyping in five family living textbooks used in Iowa

GULYA, THOMAS JOHN, Jr.
Plant Pathology
The effect of *Pseudomonas glycinea* toxin on systemic chlorosis in soybean plants

GÜNDÜZ, UFUK
Chemical Engineering
The properties of xylanase from *Aspergillus niger*

GUSTAFSON, JAMES EVAN
Industrial Relations
No thesis

HAGEMOSER, WAYNE A.
Veterinary Anatomy
Studies concerning the effects of prenatal lead exposure on visual discrimination in rats

HAGEN, RANDI LOUISE
Psychology
Behavioral and introspective manifestations of agency and communion: An exploration

HAGENSON, MARY JANE SKOGEN
Biomedical Engineering
A high efficiency flow microfluorometer: Application to bacterial flourescence

HALEY, PAUL FRANCIS
Mechanical Engineering
Design criteria for a low-speed plane cascade wind tunnel

HALL, MELVIN RICHARD
Horticulture
Firmness of strawberries as influenced by foliar and fruit applications of calcium

HALLMAN, LEO JOSEPH
Mathematics
No thesis

HANENBERGER, DONALD F., Jr.
Computer Science
No thesis

HANNA, HAROLD MARK
Agricultural Engineering
Effects of conservation tillage and practices on energy consumption for corn

HANS, CAROL WEST
Home Economics Education
Assessment of an exchange plan to measure adequacy of dietaries

HANSER, LAWRENCE MORLEY
Psychology
The interaction of length and type of rehearsal in long-term memory

HARRIOTT, EDWARD WILLIAM, Jr.
Biomedical Engineering
High frequency power amplifier design techniques
HARRIS, CHRISTINE MOODIE
Family Environment (Housing)
The relationship between housing quality, housing satisfaction, and residential adaption: A normative housing study
HARRIS, RONALD LIONEL
Nuclear Engineering
Void thermalization response of a self-powered neutron detector
HARRISON, ELIZABETH WALTERS
Home Economics Education
Home economists' role as perceived by the extension home economist and by home economics program committee members
HARTTER, DARYL EDWARD
General Graduate Studies (Biological Sciences)
No thesis
HASAN, MAHMOOD
Structural Engineering
No thesis
HAUSER, WADE RODWELL III
Agricultural Economics
Soil erosion control in western Iowa
HAWKINS, VERNIE E.
Education (Higher Education)
No thesis
HEARN, TIMOTHY FRANCIS
Biochemistry
Ribonucleic acid synthesis in preimplantation mouse embryos
HEKMAT, FIROOZ
Sociology
A study of intention to stay in the United States among the Iranian students at Iowa State University
HELVICK, JAMES PETER
Education (Research and Evaluation)
No thesis
HENDERSON, KARLA ANN
Education (Guidance and Counseling)
No thesis
HENRY, REGINA MARIE
Institution Management
Cost of use of disposable ware in school food service
HERBRECHTSMEIER, EDWARD HENRY
Geodesy and Photogrammetry
A point mass model for estimating gravity anomalies from measured geoid heights
HERZOG, ROCHELLE TENEA
Education (Higher Education)
No thesis
HIATT, DEIDRE PEGLAR
Psychology
Field independence and the use of defense mechanisms
HILLSON, THOMAS DONALD
Botany (Physiology)
Hormonal and physical factors regulating floral bud formation and development on tobacco stem explants
HO, CHUNG MAN
Statistics
No thesis

HO, PING-YU
Computer Science
No thesis
HOCKING, GUY EABY
Industrial Education
The effectiveness of the project method as a motivator for Industrial Education
HOFFMAN, EDITH M.
Education (Guidance and Counseling)
No thesis
HOLTER, JAMES ALBERT
Veterinary Pathology
No thesis
HON, CLARENCE CHI-YEUNG
Chemical Engineering
Gasification of carbon with aqueous caustic solutions
HOTZLER, BRYON LEE
Institution Management
Practices and conditions in selected large school food service systems that transport lunches, in relation to quality and safety of food
HOUGH, DONALD CLAIR, Jr.
Civil Engineering
No thesis
HULTGREN, PAUL JOHN
Metallurgy
Proton irradiation of vanadium
HUMPHREY, BEVERLY JEAN HINKLE
Entomology (Insecticide Toxicology)
Chlorinated hydrocarbon insecticide residues in ground beetles (Coleoptera:Carabidae) from Iowa cornfields and the effect of dieldrin on adult carabids
HURST, MARY SUSAN
Industrial Relations
No thesis
JAAFARI, HAMID
Agricultural Engineering
Rubber roller corn shellers for reducing mechanical damage of corn shelling
JACKSON, HAZEL DIANE
Education (Guidance and Counseling)
No thesis
JARNAGIN, JERALD LEROY
Veterinary Microbiology
Development of an agglutination procedure for use in the identification of Mycobacterium paratuberculosis
JENNINGS, JOSEPH MARSHALL
Education (Higher Education)
No thesis
JENSEN, BEVERLY ANN
Home Economics Education
Characteristics of home economic teachers and student teachers pertaining to interaction with physically handicapped persons
JENSEN, MICHAEL K.
Mechanical Engineering
Boiling heat transfer and dryout in restricted geometries
JERGENSON, DOUGLAS JAMES
Muscle Biology
Myofibrillar protein integrity and a calcium activated muscle protease in postmortem and denervated skeletal muscle
JOHNSON, EQUILLA LUKE
Education (Higher Education)
No thesis

JOHNSON, GARY MICHAEL
Poultry Nutrition
Lysine availability of differently processed blood meals evaluated by chick growth assays and a chemical method

JOHNSON, HAROLD LEVANT, Jr.
Physics
Severe storm detection

JOHNSON, MARY LOU
Geology
Natural resources of Story County, Iowa: A computer analysis

JOHNSON, RAYMOND HENRY
Education (Guidance and Counseling)
No thesis

JONES, GEORGIANNA
Nutrition
The stability of vitamin A in dehydrated model systems

JONES, ROBERT SPICER
Education (Adult and Extension Education)
No thesis

JORDAN, TERRY BERVIG
Education
No thesis

JUELSGAARD, STEPHEN GLEN
Veterinary Clinical Sciences (Reproductive Diseases)
Humoral antibody response in the neonatal foal

JUNGST, STEVEN EDWARD
Forestry (Forest Biometry)
No thesis

KAGAN, ALBERT
Animal Nutrition
The use of non-protein nitrogen for poultry

KALBASI-ASHTARI, AHMAD
Food Technology
Oat oil—its refining and oxidative stability

KAMP, HARVEY PHILLIP
Institution Management
A cost information system for the dietary department in a small health care facility

KAYEMBE, NZONGOLA
Chemical Engineering
Kinetics of the coal char-steam reaction

KELLEY, DAVID S.
Education (Higher Education)
No thesis

KEMP, JOHN J.
Industrial Relations
No thesis

KEPHART, KEITH WAYNE
Education (Higher Education)
No thesis

KERNSTOCK, KATHLEEN KAY
Veterinary microbiology
Studies on the growth responses of virulent *Treponema hyodysenteriae* in liquid medium

KHAMBATY, SHAKIR
Chemical Engineering
Crystal surface regeneration and survival of small crystals in contact nucleation

KILPATRICK, CHARLES B.
Education (Adult and Extension Education)
No thesis

KIMBLE, BARBARA KELHER
Biochemistry
Study of the action of dextransucrase from *Leuconostoc mesenteroides* NRRL B512

KIREGYERA, BEN
Statistics
No thesis

KNUTSEN, GARY LEE
Physiology
The influence of age, sex, and weight on respiratory function in the sedate canine

KOEHLER, CALVIN RALPH
Zoology (Physiology)
Effects of an acoustic stimulus upon growth antibody synthesis and leukocyte values

KOENIG, LAWRENCE NILS
Engineering Mechanics
Photoplasticity in the hot forming of metals

KOOPMAN, DAVID LEON
Education (Educational Administration)
No thesis

KOOSER, DIANA RAE TRESSLER
Education (Guidance and Counseling)
No thesis

KULKARNI, ANAND KRISHNARAO
Solid State Physics
Temperature dependence of resistivity of thin film samples of chalcogenide glasses

KWINN, KATHRYN YUHAS
Computer Science
No thesis

LADUKE, BETTIE SUE
Economics
Residential and business trip behavior in an Iowa rural community

LAIHO, KIRSI HELKA MARKETTA
Institution Management
Practices and conditions in selected small school food service systems that transport lunches, in relation to quality and safety of food

LAM, WAI CHUNG
Statistics
No thesis

LAMYORDMAKPOL, ANUCHIT
Statistics
No thesis

LAPAN, SALLY MILLER
Family Environment
Images of men and women reflected in magazine advertisements in 1962 and 1973

LAWRY, GEORGE NEWTON
Industrial Education (Industrial Vocational-Technical Education)
No thesis

LEE, SANG UK
Electrical Engineering
Evaluation of the electrical parameters of coplanar type transmission lines

LEIDNER, JOHN ROBERT
Journalism and Mass Communication
Communication practices and needs as perceived by directors and editors of state agricultural experiment stations

LELAND, BERNIE JAMES
Mechanical Engineering
No thesis

LEONE, ANTONIO
Crop Production and Physiology
The effect of N and K fertilization on the chemical composition of smooth bromegrass (*Bromus inermis* Leyss.)

LIN, HWEI-SHEN
Meat Science
The influence of pre-rigor and post-rigor processing on shelf-life of fresh pork sausage
LINN, GREGORY THOMAS
Forestry (Administration and Management)
No thesis
LITTLEFIELD, ROGER JAY
Psychology
The effect of a behavioral reward system on the perceptions of locus of control of incarcerated females
LOGEL, MARVIN LEROY
Psychology
Effects of ventral noradrenergic bundle destruction on feeding behavior in rats
LONEY, STEVEN CURTISS
Education (Educational Administration)
No thesis
LORBER, WILLIAM GEORGE
Economics
Central place systems in rural labor markets
LORENCE, JAMES CHARLES
Sanitary Engineering
Backwashing and performance of single, dual, and mixed-media wastewater filters
LUU, MINH
Mechanical Engineering
A study of transition in the unsteady shock-induced boundary layer on a flat plate
LYE, DENNIS JOHN
Bacteriology
Effects of medium constituents on the development of competence for transfection in Staphylococcus aureus 8325
MALLAS, JOHN HENRY
Education (History, Philosophy, and Comparative Education)
No thesis
MANATT, SALLY JOHNSON
Education (Curriculum and Instructional Media)
No thesis
MANKUS, PAUL JOSEPH
Physiology
The effect of oral lead on the resistance of hamsters to *Salmonella typhimurim*
MARCOTTE, ELODIE LORIS
Child Development
Self-concept of personal space in preschool children
MARKS, DOUGLAS M.
Education (Higher Education)
Attitudes toward education and their relationship to farm operator innovativeness
MARTIN, GREGORY CHARLES
Chemical Engineering
Bubble size distribution in aeration processes
MATHEWS, RONALD LEE
Biomedical Engineering
A study of a technique for measuring the membrane potentials of a single myleinated nerve fiber
MATSUI, TSURU
Statistics
Some kinetic models in biology
MAYOTTE, ALLAN CLARK
Family Environment
Effects of a group counseling model on self-concept and related variables with adult members of disadvantaged families

MCCOMAS, JOHN GREEN
Analytical Chemistry
Determination of nitrate by anion exchange with ultraviolet detection

MCCORMICK, LOIS CLARK
Home Economics Education
Test for assessing consumer responsibility concepts of middle school pupils

MCCULLOUGH, BILL D.
Education (Educational Administration)
No thesis

MCWETHY, STEVEN JOHN
Bacteriology
Bacteroides amylophilus alpha-amylase

MD TAP, ABU OSMAN BIN
Mathematics
No thesis

MEEKER, CAROL MOROTTI
Family Environment
The development of family life attitude scales: A comparison of college students and a general noncollege sample

MEESE, ANN WALSH
Education (Educational Administration)
No thesis

MELTON, BRYAN EDWIN
Agricultural Economics and Animal Breeding
Response analysis of beef feedlot gain with respect to genetic and environmental inputs

MENDEZ, HECTOR EDUARDO GONZALEZ
Economics
No thesis

MENZ, BRIAN LEE
Education (Curriculum and Instructional Media)
No thesis

MENZEL, FEROL SCHRICKER
Child Development
Effects of dominance and relevance on visual discrimination in preschool males

MILBRATH, JUDY JEAN
Nutrition
Nutrition education for older Americans: Television public service announcements

MILLER, PATRICK MICHAEL
Botany (Physiology)
Partial purification of Δ^1-pyrroline-5-carboxylic acid reductase

MILES, RICHARD DEAN
Biomedical Engineering
Transmission of vibrations from simulated arterial stenoses

MILLER, KAREN JEFFRIE
Wildlife Biology
Activity patterns and site selection in nesting blue-winged teal *(Anas discors)*

MILLER, ROBERT ALLAN
Education (Higher Education)
No thesis

MINARD, EDWIN LINCOLN, Jr.
Physiology
The effects of sex and of dietary protein levels on plasma renin activity and angiotensinogen levels in mature beagles

MOORE, JANET MAZZOLA
Education (Curriculum and Instructional Media)
Professional characteristics of educational media personnel in Iowa Public schools

MOORE, LINDA OLSON
Education (Guidance and Counseling)
No thesis

MORELAND, RUSSELL K.
Transportation Engineering
Urban noise levels and the effect on the urban community
MORGAN, SUSAN LYNNE NODLAND
General Graduate Studies (Biological Sciences)
No thesis
MORRIS, JOHN CHARLES
Sociology
Assessing the ideal community: A descriptive study of selected Iowa Communities
MORRIS, VIRGINIA LEE
Analytical Chemistry
Flow coulometric detection in the liquid chromatographic determination of phenols
MORRISON, JUDITH KLANG
Home Economics Education
Iowa women's knowledge of selected state laws affecting families
MOSCHITTO, RICHARD DOMINICK
Chemical Engineering
Gasification of coal char and lignite in an electrothermal fluidized bed reactor
MOSTAJERAN, AKBAR
Water Resources
Study of the potential for increasing plant available water in soils by the use of super slurper (starch-polyacrolonitrite)
MOTOYAMA, TETSURO
Psychology
Application of psychological scaling procedures to obtain signal detection measures
MOURER, DAVID PAUL
Metallurgy
Crystallography of preferred growth in lead-tin alloys
MOWREY, DANIEL HERBERT
Mathematics
No thesis
MURPHY, JERALD JOSEPH
Industrial Education (Industrial Vocational-Technical Education)
No thesis
NACHOD, MARY SWAIN
Nutrition
Skinfold thickness and socioeconomic status of preschool white females
NAYLOR, ANN MUSSELMAN
Nutrition
Food frequency indexes in analysis of food behavior
NEGUS, JEANNE ROHWER
Home Economics Education
An achievement test in child development for junior high school pupils
NELIN, KJELL BERT
Physics
No thesis
NELSON, BEVERLY DUNN
Industrial Education (Industrial Vocational-Technical Education)
No thesis
NELSON, STEPHEN OTTO
Solid State Physics
Deuteron nuclear magnetic resonance investigation of $LaNi_5D_x$ compounds
NELSON, VALERIE MAY
Zoology (Parasitology)
Immunochemical characterization of mouse peritoneal exudate fluid
NICHOLSON, BRENDA LUCETTE
Education (Guidance and Counseling)
No thesis

NOLAND, SHIRLEY MAXINE NELSON
Education (Adult and Extension Education)
No thesis
NOR, YAHYA MOHD
Soil Chemistry
Oxidation of elemental sulfur in soils
OBIOHA, IFEANYICHUKWU WILFRED
Food Technology
Bacteriological quality of ground beef and soy extended ground beef
OLSON, KENT DAVID
Agricultural Economics
No thesis
OLSON, LARRY LYNN
Structural Engineering
No thesis
OLSON, SHARON KAY
Industrial Relations
No thesis
OPOIEN, JAMES WAYNE
Mathematics
No thesis
ORNING, ANN PROFITT
Veterinary Microbiology
Comparison of *Klebsiella pneumonia* from mastitic and normal swine and their environment
OROZCO, ALVARO
Mechanical Engineering
No thesis
ORTALE, DAVID JEROME
Education
No thesis
OSBORN, NANCY MAE
Sociology (Anthropology)
The Clarkson site (13WA2): An Oneota manifestation in the Central Des Moines River Valley
OVERFIELD, JAMES RALPH, Jr.
Animal Nutrition
Nutritional regulation of insulin secretion in sheep
OWEN, MICHAEL DAVID
Botany (Physiology)
Interaction of herbicides and *Fusarium oxysporum* on *Glycine max* L. root injury
PAGEL, KIMBERLEY BRENT
Education (Guidance and Counseling)
No thesis
PALACIOS-NIEVES, JOSE
Agricultural Engineering
Estimation of evapotranspiration of corn in Iowa using a soil moisture balance
PALS, DOUGLAS ALLEN
Animal Nutrition
No thesis
PANMUNIN, WANNA
Sociology
On Morality and health facilities in Thailand: A health indicators perspective
PAREJA, GILDA PIAGGIO
Statistics
No thesis
PARK, KYUNG NAM CHUNG
Nutrition
Beta-carotene utilization in young rats modified by excess tocopherol and dietary fat

PARRA-COA, OSWALDO RAFAEL
Crop Production and Physiology
Effects of nitrogen fertilization and cutting management on yield, botanical composition, and quality of birdsfoot trefoil—tall fescue swards
PASHAZADEH, MONAJEMI MOHAMMAD B.
Statistics
No thesis
PAULSON, ROBERT JAMES
Food Technology
A comparison of wild and domestic turkeys
PAULSON, STEPHEN KENNETH
Soil Engineering
The strength, structure, and mineralogy of selected Hawaiian lateritic soils
PAYNE, ELAINE IRENE JOHNSON
Psychology
Locus of control and the attribution of responsibility for depression
PEGLOW, STEVEN GILBERT
Aerospace Engineering
Turbulence modeling applied to the decay of a trailing vortex
PETERSON, GREGG DUANE
Education (Higher Education)
No thesis
PETERSON, JOHN KENNETH
Industrial Engineering
Maintenance aspects of a research equipment management program
PETERSON, MICHAEL ANTHONY
Education (Educational Administration)
No thesis
PITZ, JANE ANDREWS
Education
No thesis
PFANNEBECKER, LARRY DON
Education (Educational Administration)
No thesis
PHILLIPS, TERESA ANN
Biochemistry
Partial characterization of smooth muscle tropomyosin
PINSKI, KENNETH ROBERT
Statistics
No thesis
PITLO, VIVIAN FISCHER
Education (Guidance and Counseling)
No thesis
PONDER, WENDELL WAYNE
Statistics
No thesis
PORTER, JANEANN
Journalism and Mass Communication
Readership of the Iowa Falls Citizen—A comparison of two methods
POTHOVEN, KEITH EDWIN
Mathematics
No thesis
POWERS, EDWARD JOSEPH
Chemical Engineering
Thermochemical water splitting cycles: Oxygen liberating reactions
PRICHARD, ROBERT DONALD
Education
Selection techniques and level of qualifications of U. S. Navy shipboard safety officers

PUNDT, KATHRYN JEAN AHRENS
Education (Physical Education)
No thesis

PUTNAM, JAMES NATHANIAL II
Agricultural Economics
Adjusting land installment contract terms to meet the needs of low-equity farmers

RAMASWAMY, VENKATACHALAM
Food Technology and Veterinary Clinical Sciences (Veterinary Medicine)
Viability of Toxoplasma gondii in relation to processing of meat

RAMM, CARL WILLIAM
Forestry (Forest Biometry)
No thesis

RAMSDELL, SHERYL LYNN
General Graduate Studies (Biological Sciences)
No thesis

RATCLIFF, NICHOLAS HARRY
Industrial Education (Industrial Vocational-Technical Education)
No thesis

RAUSCH, JOHN BERNARD
Metallurgy
The lattice parameters and structures of iron-silicon single crystals and the elastic constants of Fe_3Si

REDDY, KUNDUR ARJUN
Biomedical Engineering
Cardiopulmonary resuscitation training device modifications and a hospital electrical safety study

REED, RINALDA
Education (Guidance and Counseling)
No thesis

REESE, JOSEPH LEE
Geology
The size, shape, extent and continuity of the coal field at Madrid, Iowa

REEVES, MELVIN DOUGLAS
Structural Engineering
Service load tests on full-scale highway truss bridges, including fatigue tests and static tests on eyebars

RETNADHAS, C.
Computer Science
No thesis

REZAI, ABDOLMAJID
Plant Breeding
Chromosome studies in interspecific crosses of hexaploid oats

RHEE, JEONG J.
Economics
Economic growth, technological changes, and environmental problems in Japan

RICH, MICHAEL ANTHONY
Geology
Foraminifera of the Graneros and Greenhorn Formation (Upper Cretaceous) from one exposure near Sioux City, Iowa

ROCKWELL, DWIGHT
Statistics
No thesis

RODENBORN, MARY ANNE
Education (Guidance and Counseling)
No thesis

ROHRET, MICHAEL GEORGE
Industrial Relations
No thesis

ROSE, ANGELA DIANE
Education (Higher Education)
No thesis
ROVANG, DOUGLAS CEDRIC
Sanitary Engineering
Regional evaluation of municipal water pollution control facilities in the upper Skunk River basin
RUDEN, DONNA JEAN TOMLONOVIC
Education (Higher Education)
No thesis
RUE, STEVEN A.
Education (Educational Administration)
No thesis
RUNGE, MARTIN LUTHER
Psychology
An attributional analysis of perceived aggression
SACKETT, RONALD JOSEPH
Industrial Education
No thesis
SAFA-ESFAHANI, AHMAD REZA
General Graduate Studies (Biological Sciences)
No thesis
SAMUELS, BETTE JEAN
Family Environment
Knowledge and use of consumer credit by urban wives
SANDERS, JOHN MICHAEL
Soil Management
Erosion control cropping systems for corn in western Iowa
SATO, MUNEHARU
Animal Breeding
The influence of dominance and gene interaction on egg production and other traits in laying hens
SAYED, SALAHEDDIN ABDALLAH
Chemical Engineering
Experimental vapor-liquid equilibrium data and statistical consistency tests
SAYGIDEGER, ORHAN
Agricultural Economics
No thesis
SCHERMER, DOUGLAS GEORGE
Education (Educational Administration)
No thesis
SCHIAVI, WILLIAM FRANCIS
Ceramic Engineering
Interdiffusion in the Er_2O_3-HfO_2 system
SCHMIDT, BARBARA JONES
Education (Adult and Extension Education)
No thesis
SCHNEIDER, JAMES FRANZ
Animal Breeding
Heterosis, combining abilities and maternal ability estimated from single-crosses among four breeds of swine
SCHOGER, STEVEN CRAIG
Sanitary Engineering
The optimization of vacuum filtration of a municipal wastewater sludge
SCHRECK, WENDY LYNN
Psychology
Effects of concurrent tasks on the precategorical acoustic store

SEELEY, BRIAN DEXTER
Biomedical Engineering
Effect of geometry on pressure losses across models of arterial stenoses
SELBERG, LES PAUL
Structural Engineering
No thesis
SELLERS, GLENN WOOD, Jr.
Electrical Engineering
The design of an interface between a minicomputer and a high speed recirculating data network
SEVERNS, GARY ALAN
Mechanical Engineering
No thesis
SHARP, GEORGE RAYMOND
Industrial Education
No thesis
SHARP, MARILYN MARIE LEFLER
Home Economics Education
Determining vocational training needs of educable mentally retarded individuals: Follow-up study
SHEFFIELD, VIRGINIA KAY ANDERSON
Family Environment
Managerial standard setting and family resource distribution
SHEPHARD, DELBERT AUSTIN
Education (Educational Administration)
No thesis
SHOFF, MARTHA E.
Education (Guidance and Counseling)
No thesis
SHU, VEN-SHION
Statistics
No thesis
SIFAW, AYOB AMAR
Geodesy and Photogrammetry
No thesis
SIGMON, STEVEN VICTOR
Geodesy and Photogrammetry
No thesis
SILVA FILHO, ANTONIO DE PADUA FERREIRA DA
Veterinary Clinical Sciences (Veterinary Surgery)
Evaluation of the intravenous administration of Xylazine hydrochloride on cardiopulmonary function in the bovine species (*Bos taurus*)
SKEWES, KENNETH WILLIAM, Jr.
Computer Science
No thesis
SMITH, TODD GALE
Journalism and Mass Communication
A descriptive analysis of the American Broadcasting Company's London News Bureau
SMITHSON, LELAND DENNY
Transportation Engineering
No thesis
SNYDER, FRANK COOK
Industrial Education
No thesis
SONESON, SONIA BETH
Child Development
Development of moral intentionality in young children

SORENSEN, JAMES PHILLIP
Structural Engineering
No thesis
SORENSEN, LINDA G.
Education (Guidance and Counseling)
No thesis
STAGEMAN, GRACE ADELE
Institution Management
Equipment requirements in the machine washing of permanent tableware
STALLMO, DAVID CHARLES
Computer Science
No thesis
STEWART, DENNIS ROBERT
Zoology (Physiology)
Relaxin content of cytoplasmic granules from porcine corpora lutea of late pregnancy
STOCKFIELD, ROBERT L.
Journalism and Mass Communication
A photographic exploration of the aged in a small Iowa town
STODDARD, SAMUEL III
Geodesy and Photogrammetry
No thesis
STOLL, DANIEL Lee
Industrial Relations
No thesis
STOLP, RICHARD NEIL
Earth Science
No thesis
STOOKEY, RONALD GENE
Industrial Relations
No thesis
STOOP, JOHN FRANCIS, Jr.
Education (Educational Administration)
No thesis
STRACKE, ROBERT JOSEPH
Sanitary Engineering
Biological treatment of a toxic industrial waste
STREFF, THOMAS JAMES
Computer Science
No thesis
STUART, SHARON HOLDERBY
Child Development
Achievement motivation of preschool children and their parents
STUMME, PATRICIA COLVIN
Home Economics Education
Individualized-independent study approach to nutrition education for young adults
SUCHOMEL, ROBERT RICHARD
Ceramic Engineering
Effects of temperature and microstructure on the elastic properties of selected Eu_2O_3-HfO_2 composition
SURAINRUNGSIKUL, KITIPONG
Agricultural Economics
No thesis
SVEUM, WILLIAM HENRY
Bacteriology
A new method for the detection of salmonellae in foods and feeds
SWINTON, SUSAN GAYE DRALLE
Education (Guidance and Counseling)
No thesis

SYLVESTER, HELEN ROBERTA JEANNE
Education (Elementary Education)
No thesis
TEGBE, T. SAMUEL BABATUNDE
Animal Nutrition
Evaluation of single cell protein (SCP) using pigs
TEMPLETON, CLAUDIA DARNELL
Education (Guidance and Counseling)
No thesis
TESSMER, GEORGE WALTER
Biochemistry
Substrate specificity of phosphorylase kinase as determined with synthetic peptides
THANGAM-BABU, POTTI V.
Aerospace Engineering
Solution bounds to certain initial value problems
THOMAS, STEPHEN HAROLD
Plant Pathology
Population fluctuations of plant parasitic nematodes under different tillage systems in corn
THOME, PETER
Zoology (Physiology)
Selected stress responses to high intensity monotonic sound in the juvenile hooded rat
THOMPSON, LOLA PATRICIAH
Education (Guidance and Counseling)
No thesis
THORIUS, JAMES DEAN
Education (Higher Education)
No thesis
TIGGES, MARY CATHERINE
Education (Educational Administration)
No thesis
TIMBERG, BERNARD MAHLER
Journalism and Mass Communication
Voices of Iowa: A descriptive thesis
TIMM, LEONARD WILLIAM
Structural Engineering
Ultimate load tests of a modified Parker type high truss bridge
TIMM, MARY FAITH MOORE
Child Development
Developmental differences in preschool children on visual discrimination tasks
TITUS, PATRICIA MAHONEY
Home Economics Education
Development of criterion-referenced test for adult learner module
TORRENCE, ROBERT CHARLES
Education (Educational Administration)
No thesis
TULLY, CHRISTOPHER RAYMOND
Organic Chemistry
A study of the photochemistry of phenylselenophenes and phenyltellurophene and attempted syntheses of selenepins and tellurepins
TURNER, LANA FAE
Statistics
No thesis
VALENTA, HARRY LAWRENCE, Jr.
Biomedical Engineering
Correlation of canine electroencephalographic activity during surgical anesthesia
VANBUER, DARREL J.
Computer Science
No thesis

VANDER SANDEN, JERRY MYRON
Animal Production
No thesis
VAN EE, GARY RICHARD
Agricultural Engineering
Development of a feather chopper pump for handling poultry waste
VAN MAREL, MARY JANE
Home Economics Education
Attrition of transfer students in home economics
VARLAND, KENNETH LAVERNE
Wildlife Biology
Herd organization and movements of elk in Wind Cave National Park, South Dakota
VATANYOO, RUMPHA
Veterinary Pathology (Veterinary Toxicology)
No thesis
VORHEES, MARY PECK
Industrial Relations
No thesis
VOSBURG, SONJA ALICE
Education
No thesis
WAINWRIGHT, RAYMOND PARR
Agricultural Engineering
A variable speed moldboard plow
WALLACE, SYLVIA AGOSTA
Home Economics Education
Post-secondary fashion merchandising programs and in-service needs for teachers
WALLER, LINDA ANN HEERE
Nutrition
Dietary fat and hepatic, cardiac and serum cholesterol in adult rats
WALLINGA, CHARLOTTE RAE
Child Development
Creativity in 10- to 11-year old children and their parents
WATSON, KARILEE FREEBERG
Education (Curriculum and Instructional Media)
Developing higher order questioning skills through the use of the Socratic Method
WEBER, CLEMENCE JOSEPH
Agricultural Economics
Past entry adjustments and financial progress of 1959-60 entrants into Iowa farming
WEBER, DENNIS ALLEN
Electrical Engineering
Computer simulation in mixed abc and dq variables of a generator and external power and control circuitry for stability studies
WEDERQUIST, DONALD LOUIS
Industrial Education (Industrial Vocational-Technical Education)
No thesis
WEIR, MURIEL ANN
Journalism and Mass Communication
Pamphlet No. 5 and the freedom to publish at Iowa State College
WHITED, DENNIS EUGENE
Soil Engineering
Chemical additives as compaction aids for fine-grained soils
WHITING, LARRY ROBERT
Journalism and Mass Communication
Mass media gatekeepers and community development: Aspects of role, perceptions, and performance
WHITMER, JOHN MIRL, Jr.
Economics
No thesis

WHITNEY, GLENN CRAIG
Education (Guidance and Counseling)
No thesis
WICKERSHAM, WILLIAM LEE
Journalism and Mass Communication
Iowa's open meetings and public records laws: A review and analysis
WILLENBORG, DALE BERNARD
Computer Science
No thesis
WILLIS, DEAN ALAN
Sanitary Engineering
Variable declining-rate filtration of secondary effluents
WITTEN, ARTHUR LEE, Jr.
Fisheries Biology
A study of the impact of selected bank stabilization structures on game fish and associated organisms
WOLF, RONALD EARL
Computer Science
No thesis
WONDERLICH, ESTHER GRACE ENGELHARDT
Home Economics Education
Needs of home economics teachers of adult homemaking classes
WONDERLICH, JANET VANDERLINDEN
Child Development
Cooperative behavior of friend and nonfriend pairs of preschool children
WONG, BERT CARL
Biomedical Engineering
Development of a heat transfer method for ovulation detection in the sheep
WONG, WING-SUM DOMINIC
Food Technology
An improved method for the analysis of peroxide types in oxidized fatty ester mixtures
WYNN, CASSANDRA ESTELLE
Journalism and Mass Communication
A readership study of a community weekly newspaper—the Iowa Falls Citizen
WYNNE, RICHARD THOMAS
Agricultural Climatology
Soil moisture characteristics of some common Iowa soils
XUMSAI, PONGSI
Town and Regional Planning
Studies for development plan for Bangkok, Thailand
YANG, KYONG-HA
Soil Engineering
Shear strength of chemically modified fine-grained soils
YEH, YU-SUNG
Chemical Engineering
Preliminary kinetics of high-temperature reaction of chlorine and steam
YOCKEY, KATHLEEN MARY
Family Environment
Residential alterations and additions and housing ---neighborhood satisfaction
YOST, WILLIAM MICHAEL
Nutritional Physiology
Propionic acid production from a high-grain diet in the bovine
YU, FU LAI
Economics
No thesis
YUNGCLAS, WILLIAM ROBERT
Education (Guidance and Counseling)
No thesis

YUSOFF, MOHAMMED BIN
Agricultural Economics
No thesis

YUVA, ROBERT GARY
Town and Regional Planning
An analysis of urban land banking as a growth management technique

YUVA, THOMAS ALLEN
Industrial Relations
No thesis

ZARGHAMI, FATEMEH
Education (Guidance and Counseling)
No thesis

ZIMMERMANN, BARBARA JEAN
Veterinary Microbiology
Characterization of the antibody response of swine to *Mycoplasma hyosynoviae* vaccination

ZUMBRUNNEN, JAMES ROBERT
Statistics
no thesis

ADAMS, LEOLA
Home Economics Education
Teacher preparation as a factor of teacher performance

ADOLPHSON, DOUGLAS GUY
Inorganic Chemistry
Synthesis and crystal structure of some novel phases involving metal-metal bonding

AITCHISON, THOMAS EDWARD
Nutritional Physiology
Nitrogen utilization by lactating dairy cows

AL-DUJAILI, HAMZA KHUDHAIR
Nuclear Engineering
The formulation and analysis of the nine-point finite difference approximation for the neutron diffusion equation in cylindrical geometry

ALEONG, JOHN
Statistics
Aspects of simultaneous inference

ALT, KLAUS FRIEDRICH
Agricultural Economics
An economic analysis of field crop production, insecticide use and soil erosion in a subbasin of the Iowa River

AMPRATWUM, DAVID BOAKYE
Agricultural Engineering
Heat and moisture transfer and exchange in bulk grain

ANDREWS, RICHARD WAYNE
Analytical Chemistry
The voltammetric deposition and stripping of selenium at gold electrodes

APT, PATRICIA HARPER
Education (Adult and Extension Education)
Adult learners and higher education: A study of interests and needs in rural Iowa

ARCHER, THOMAS MICHAEL
Agricultural Education
Dimensions of perceived importance of the problem-solving principle in agriculture and agribusiness education

ASPEGREN, EVA CHRISTINA ELISABETH
Home Economics Education
Evaluation of a pilot family planning project in the Iowa Cooperative Extension program

AUTH, JAMES CONRAD, Jr.
Zoology (Physiology)
Effects of exercise upon circulating thyroxine, serum and hepatic lipid concentrations, heart, and seminal vesicles in rats and of age and exercise upon circulating thyroxine in humans

BAJAJ, RAM
Metallurgy
Radiation damage in vanadium doped with oxygen

BAKER, DOUGLAS JESSE
Plant Breeding
Combining ability for forage characteristics in reed canarygrass, *Phalaris arundinacea* L.

BAMBENEK, THEODORE ROY
Mathematics
Properties of Q(X,P) spaces

BANWART, WAYNE LEE
Soil Fertility
Volatilization of sulfur from soils and animal manures

BAREL, DIRK
Soil Chemistry
Foliar application of phosphorous compounds

BAYNE, NANCY ELIZABETH
Psychology
Sex-typing, parental distance, and cognitive style

BISCHOF, CHARLES JACOB
Nuclear Physics
Gamma-ray decay schemes for ^{93}Kr, ^{93}Rb, and ^{93}Sr

BOHLING, RICHARD WAYNE
Soil Fertility
The influence of potassium fertilization and plant population upon the performance of several corn hybrids

BROCKWAY, JAMES MARTIN
Sociology
Structural effects and fertility behavior in the United States of America: An elaboration of the demographic regulation theory

BUDNIK, THOMAS JOSEPH
Education (Curriculum and Instructional Media)
An estimate of the reliability of the technique of increasing educational accountability through goal analysis

BUHR, KENNETH LEE
Plant Breeding
Inheritance of time to flowering, time to physiological maturity and growth habit in soybeans grown at a tropical latitude

BULLARD, ROBERT DOYLE
Sociology
Voluntary participation: Implications for social change and conflict in a community decision organization

BURLAMAQUI, PAULO FERNANDO
Crop Production and Physiology
Variation in soybean yield components in relation to genotype and productivity level

BURNS, HARRY ALAN
Physical Chemistry
The calculation of the second virial coefficient for dipolar and quadrupolar polyatomic gases

CAPUTO, COLLEEN CLUFF
Home Economics Education
Validation of a teaching performance device

CARLSON, GERALD MICHAEL
Biochemistry
Control of phosphorylase kinase activity by autophosphorylation and neutral salts

CARLSON, SUSAN ANDERSON
Nutrition
Influence of meal pattern and dietary fat on cholesterol metabolism in adult rats recovering from undernutrition

CARSON, THOMAS LEE
Veterinary Pathology (Veterinary Toxicology)
Auditory and visual discrimination learning in sheep prenatally and postnatally exposed to lead

CARTER, RICHARD IRA
Agricultural Education
Professional competencies needed and possessed by beginning teacher educators in agricultural education

CHAN, YIE LANG
Agricultural Economics
Farm size and cost functions in relation to machinery technology in North Central Iowa

CHAN, YUK-CHARN
Biochemistry
0-(2-hydroxyethyl)-amylose as the substrate of porcine pancreatic α - amylase action: Structural analysis of 0-(2-hydroxyethyl)-maltooligosaccharides

CHEN, TAN-PING
Chemical Engineering
Bed and contact resistances in an electrically conducting fluidized bed

CHENG, CHIN-SHENG
Meat Science
Biochemical studies of postmortem aging, calcium ion and heating on bovine skeletal muscle proteins

CHEUNG, LAP MING
Physical Chemistry
The multiconfiguration self-consistent field method for many-electron systems and its application to the dissociation of ethylene

CHRISTENSEN, JAMES EARL
Sociology
An exploratory analysis of the substitutability of outdoor recreation activities

CHYR, SHUANG-CHINQ
Animal Breeding
Estimation of Holstein cows' milk producing ability

CLAMBEY, GARY KENNETH
Botany (Ecology)
A survey of wetland vegetation in northcentral Iowa

COLETTE, WILLIAM ARDEN
Agricultural Economics
Impact of water right constraints on the regional allocation of agricultural production

COZAD, RALPH LARRY
Education (Educational Administration)
A planning model for the creation and implementation of an educational program in a new high school facility

CRAWFORD, RICHARD DWIGHT
Wildlife Biology (Ecology)
Breeding biology of American Coots in relation to age

CRUM, GLENN HARRY
Botany (Aquatic Plant Biology)
Distribution, taxonomy, and ecology of charophytes in Iowa

CULP, CHARLES HENRY III
Solid State Physics
Threshold switching in the amorphous semiconductor $As_{15}Te_{70}Ge_{15}$ and in the organic semiconductor melanin

DAYTON, WILLIAM RANDALL
Biochemistry
Purification and some properties of a CA^{2+}-activated muscle enzyme that removes Z-disks

DEVORE, THOMAS CARROLL
Physical Chemistry
Spectroscopy of transition metal species in rare gas matrices I. Vanadium metal II. Sulfides III. Carbonyl complexes IV. Dinitrogen complexes V. Homonuclear diatomic molecules

DOCTOR, PAMELA ANANIS
Statistics
Some sequential inference problems for Polya urns

DOYLE, RICHARD LINN
Education (Educational Administration)
Effectiveness of individually guided education schools as measured by indicators of quality

DUEA, JERRY MAX
Education (Educational Administration)
As assessment of provisions for practical teacher education experiences and research in public, private and laboratory schools

DUNCAN, MARVIN R.
Agricultural Economics
A programming model for analysis of nonmetropolitan hospital services systems and application of the model

DVOSKIN, DAN
Economics
A national model of energy use in agricultural production

ECKELS, DAVID E.
Solid State Physics
Electrical switching in bulk samples of 0.15As-0.12-Ge-0.73Te glass

EGLI, STEVEN EDWARD
Elementary Particle Physics
Minimal Regge model for meson-baryon scattering: Duality, SU(3) and phase-modified absorptive cuts

EICKHOFF, LUVERN ROBERT
Education (Research and Evaluation)
Perceived effects and relationships of multi-assessor feedback on modifying educator performance behavior

ELFAR, ALY ABD ELGHAFFAR
Engineering Valuation
Valuation of machinery and equipment for industrial properties

EL-HURANI, MOHAMED HAITHAM MAHMOUD
Economics
Economic analysis of the variation and development of the wheat subsector of Jordan

ELTOUNY, ALMOEZ LEDIN ELLAH MOHAMMAD SHAWKAT
Engineering Evaluation
A guide to industrialization among selected nations

FAUNGFUPONG, SUPOT
Crop Production and Physiology
Effects of prolonged low light intensity and photoperiod on grain yield and some other agronomic characteristics of corn *(Zea mays* L.*)*

FEHR, ROBERT LEE
Agricultural Engineering
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RELATIONSHIP OF CORN ROOTWORN TOLERANCE TO YIELD IN THE BSSS MAIZE POPULATION[1]

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ABSTRACT. Sixty-four unselected single-cross hybrids of maize (*Zea mays* L.) were evaluated for yield and for root traits associated with tolerance to corn rootworm *(Diabrotica spp.)*; i.e., rootworm damage, root size, and secondary root development. Yield evaluations were made in paired-row plots on rootworm-infested soil where one row was treated with an insecticide and the other row left untreated. Rootworm feeding depressed yields and increased root lodging significantly in the untreated plots. Hybrids did not vary for the amount of yield reduction incurred. Larger root systems seem to be associated with higher yields, but no relationship was evident between yield and secondary root development.

INTRODUCTION

Tolerance in maize (*Zea mays* L.) to the corn rootworm complex [*Diabrotica virgifera* Le Conte, western corn rootworm; *D. longicornis* (Say), northern corn rootworm; and *D. undecimpunctata howardi* Barber, southern corn rootworm] has been found in several sources including inbred lines (Eiben and Peters, 1965; Fitzgerald and Ortman, 1965), plant introductions (Wilson and Peters, 1973), various exotic strains (Melhus, Painter, and Smith, 1954; Fitzgerald and Ortman, 1964), and synthetic varieties (Owens, Peters, and Hallauer, 1974). Traits that have been useful indicators of tolerance include percentage root lodging, size of root systems, and secondary root development (Eiben and Peters, 1962; Ortman and Gerloff, 1970). Genotypes with larger root systems and a higher degree of secondary root development tend to root lodge less readily and thus should tend to yield more in environments conducive to severe root lodging. It is not known whether root size and secondary root development are positively correlated with yield when root lodging does not occur. If such a correlation did exist, especially in the absence of rootworm infestations, then selection for these traits would result in improvement for yield as well as rootworm tolerance.

Also of interest is whether genotypes vary for the amount of yield reduction incurred by rootworm feeding. If such variation does exist, then selection of those genotypes sustaining the least yield reduction would be valuable. This information also would be useful in determining which genotypes and how many to use for insecticide trials.

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The objectives of this research were to estimate the effect of rootworm injury on yield and root lodging in a random set of single-cross hybrids; to determine the correlations of rootworm damage, root size, and secondary root development with yield; and to determine if these hybrids varied for the amount of yield reduction sustained from rootworm injury.

MATERIALS AND METHODS

Plant material used was a set of 64 unselected single-cross hybrids developed from random inbred lines selfed out of Iowa Stiff Stalk Synthetic (BSSS). These hybrids were planted in two types of experiments in 1972 and 1973. One experiment (type A) was a split-plot design in which whole plots (hybrids) were arranged in an 8 x 8 triple lattice. The two subplots consisted of an insecticide-treated plot and an untreated plot. In 1972 the insecticide used was fonofos applied pre-emergence at the rate of 1.12 kg AI/ha. Because fonofos did not provide complete control, carbofuran was applied in 1973, both pre-emergence and as a sidedress at cultivation time. Both carbofuran treatments were applied at the rate of 1.12 kg AI/ha. Each whole plot consisted of two, one-row subplots, which were 6.1 m long with 76-cm row width and 25-cm plant spacing. All hills had one plant except end hills, which had two, giving a total of 27 plants per plot and an approximate plant density of 51,891 plants/ha. Plots were hand harvested, ears were dried, and weight of shelled corn recorded. After harvest a sample of roots was dug to obtain an estimate of rootworm damage in treated and untreated plots. One root was dug from both subplots of every third whole plot, giving a total of 64 roots from both treated and untreated plots. Percentage root lodging also was recorded.

The experiment was analyzed as a randomized complete block with split plots because separate lattice analyses of treated and untreated plots showed no gain in efficiency for the lattice design. Phenotypic and genotypic correlations between root lodging and yield were calculated from variance and covariance components by using formulae suggested by Mode and Robinson (1959).

In the other experiment (type B), hybrids were arranged in an 8 x 8 triple lattice. Each plot was of the same size and plant density as in a type A subplot. Information on root traits was obtained from these experiments. After anthesis, the roots of three random competitive plants were dug from each plot, washed, and rated on a 1 to 6 scale for rootworm damage, root size, and secondary root development. A rating of 1 indicated the most favorable condition; i. e., no rootworm damage, very large root size, or a well-developed secondary root system, and a rating of 6 indicated the opposite extremes. Percentage root lodging was also recorded. The experiment was analyzed as a randomized complete block because the lattice analysis was not more efficient.

Plot locations for both types of experiments were at Dayton, Iowa, except the 1972 type A experiment, which was at Garnavillo, Iowa. Rootworm infestations were enhanced by late planting a "trap crop" of maize the year before planting the experiment. This procedure has been shown to be effective for increasing rootworm populations (Hill and Mayo, 1974).

Phenotypic and genotypic correlations between root traits and yield were obtained by using methods described by Suwantaradon (1974).

RESULTS AND DISCUSSION

As expected, analyses of variance over both years (Table 1) show that years, hybrids, and hybrid by year interactions all produced significant effects on yield. The significant treatment effect indicates that rootworm feeding reduced yield significantly. Of prime importance is the nonsignificant treatment by hybrid interaction. This suggests that all hybrids sustained about the same yield reduction from rootworm feeding. Therefore, selection for genotypes that show

less yield reduction would probably not be very effective. Also, the use of one hybrid should be a valid approach in an insecticide evaluation trial. Increasing the number of replications or environments would have increased precision, and possibly a significant treatment by hybrid interaction would have been detected. Such an investment of resources, however, may be impractical in many breeding or evaluation programs.

Table 1. Analysis of variance of yield obtained from 64 single crosses grown in 2 years in split plots where subplots were untreated and treated with a rootworm insecticide.

	D.F.	M.S.
Years (Y)	1	15433173**
Reps/Years	4	4425870
Hybrids (H)	63	1515599**
H x Y	63	406456**
Error A	252	278345
Treatment (T)	1	7778313**
T x Y	1	1253402**
T x H	63	128249ns
T x H x Y	63	171300**
Error B	256	119010

**Significant (P = .01).

Overall means for rootworm damage ratings, yield, and percentage root lodging are given in Table 2. Rootworm populations were high in 1972, resulting in high damage ratings even in the insecticide-treated plots. Even though control was not satisfactory, yield declined by 11.3%, and root lodging in the untreated plots was more than four times that in the treated plots. Because complete control was not achieved, this was an underestimate of total loss attributable to rootworm. Smaller rootworm populations resulted in lower damage ratings in 1973, but excellent control was achieved in the treated plots. Yield was reduced by 5.6%, and root lodging in the untreated plots was more than three times that in the treated plots. All differences were significant (P = .01). These loss estimates did not include losses resulting from lodged plants that would have been missed by mechanical harvesting because all plots were hand harvested.

Table 2. Mean rootworm damage rating, yield, and root lodging in insecticide-treated and untreated plots.

		Rootworm[a] damage rating (1-6)	Yield (q/ha)	Root lodging (%)
1972	Treated	4.3	54.2	5.9
	Untreated	5.2	48.1	25.7
	Difference	0.9	6.1	19.8
1973	Treated	1.2	46.3	2.2
	Untreated	3.3	43.7	6.9
	Difference	2.1	2.6	4.7

[a]1 = no damage, 6 = severe damage

Correlations between root lodging and yield (Table 3) are small and nonsignificant in all instances except one. The low correlations in the treated plots would be expected because the insecticide treatment reduced variability for lodging. The small amount of lodging in the 1973

experiments occurred after grain filling, which probably would not affect yield and which could explain the lack of correlation in the 1973 untreated plots. Severe lodging in the 1972 untreated plots, occurring during the boot stage, explains the significant correlation in that case.

Table 3. Phenotypic (r_p) and genotypic (r_G) correlations of yield with root lodging. Only phenotypic correlations are tested for significance.

		Root lodging		
		1972	1973	Combined
Yield (treated)	r_p	0.04	-0.19	-0.14
	r_G	-0.10	-0.03	0
Yield (untreated)	r_p	-0.30**	-0.15	-0.13
	r_G	-0.19	0.03	0

**Significant (P = .01).

Significant yield reductions, combined with nonsignificant correlation of root lodging with yield, are evidence that rootworm feeding may reduce yields even though it does not result in root lodging. This has implications for breeding tolerant varieties because many tolerance breeding programs are directed principally toward reducing root lodging. A more effective program also would include selection for genotypes that sustain lesser yield reduction if variability was available from which to select. Determination of the ways by which rootworm damage effects yield would also benefit the plant breeder. For example, if rootworm injury reduced yield by opening infection courts for pathogens, the breeder could also select for resistance to the pathogen.

Table 4 lists phenotypic and genotypic correlations of yields obtained in treated and untreated plots with the three root traints measured. Neither of the yield measurements was correlated with root damage nor secondary root development. The lack of correlation with root damage can be attributed to the absence of variability for this trait; i. e., a negative estimate of genotypic variance was obtained, thus could not be extrapolated to situations where genotypic variability for root damage was large. Secondary root development, however, was not correlated with yield despite ample variability. This suggests that selection for this trait should not result in any change in yield potential. In contrast to these traits, root size showed significant negative correlations with yield, suggesting that selection for larger root systems (or smaller root size ratings) would also result in higher yield potential. This correlation is as strong in treated (where little lodging occurred) as in untreated plots, indicating that larger root systems are associated with yield increase even in the absence of appreciable rootworm-induced lodging. Therefore, the yield advantage of a larger root system must result, not only from better physical support of the plant, but also from some other improved function of the root; e. g., uptake of water and nutrients.

Table 4. Phenotypic (r_p) and genotypic (r_G) correlations between yield and three corn rootworm tolerance traits. Only phenotypic correlations are tested for significance.

		Root damage rating	Root size rating	Secondary root rating
Yield (treated)	r_p	0.17	-0.26*	-0.02
	r_G	0	-0.51	-0.02
Yield (untreated)	r_p	0.04	-0.23*	-0.01
	r_G	0	-0.46	0.02

*Significant (P = .01).

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